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Infrastructure Management System

Preparation of Case-Study

Final Report

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Executive summary

This Final Report for the preparation of the Case-Study for Transport Management Development Program, an Infrastructure Management System (IMS), includes project description, the initial findings, description of the Infrastructure Management System; the data and analysis used and outlines for the Training Package to be used in the training of decision-makers. The agreements approved by both parties have been included as appendices in this report.

Chapters 1 and 2 describe the background and need of the Project and the organizational structure of the Project.

Chapter 3 gives basic description of the Infrastructure Management Systems (IMS), including system description, models, input data and analysis of results.

The proposed Training Package is described in Chapter 4. The basic examples to be used in training are included. Chapter 5 concludes this study and summarizes recommendations for further studies.

This very ambitious project was carried out with success. The original objective was to create a software training package to use in the World Bank's training program for highway management i.e. optimizing the economical management of nation's pavements and bridges. However the result was a useful software package to be used in road administration's daily strategy planning purposes instead of only for training purposes. The results so far seem very promising to be used in the Finnish Road Administration's strategy setting.

The developed tool is meant to be for the use of, especially, the top managers of the road administration but also for the lower level managers and paving and bridge engineers. It brings the optimization and economical points of view very clearly into decision making at the network level. The framework of the software basically can be used with optimizing of any infrastructures of the society with the following notion; data collection and modelling work has to be done beforehand.

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1 INTRODUCTION

The Memorandum of Understanding between the Government of Finland (GOF) and the Economic Development Institute of the World Bank (EDI) was signed in Helsinki, December 18, 1992. The Memorandum of Understanding states the framework for co-operation of the both parties that would focus on a transport training program for senior sector managers and trainers from Republics of the Former Soviet Union (Annex 1). As part of the training program would be the Case-Study for Transport Management Development Program (TMDP).

The Terms of Reference for the Case-Study on Infrastructure Management System are attached as Annex 2. The Case-Study would be immediately used as training material for the TMDP.

The Finnish proposal was to introduce the existing Pavement Management (PMS) and Bridge Management (BMS) Systems and to modify and couple them into one system, **Infrastructure Management System (IMS)**, in order to optimize simultaneously bridges and pavements under the same budget and other constraints. As such the system will comprehensively consider all the main expenditure items associated with the network under consideration, i.e. bridges and pavements in this case of road networks. Furthermore, the system incorporates discounted cash flow techniques, so that investment efficiency indicators can be estimated for each investment alternative associated with a pre-specified level of budgetary availability.

The Case-Study was financed by the Government of Finland. The total project cost was USD 120000. EDINU will bear the additional costs to be incurred with the editing, translation, publication and diffusion of the Case-Study.

The contents of the case-study were:

- modification of the six sub-models in PMS to be used for both the pavements and the bridges; three for each structure
- estimation and calculation of the current condition data, deterioration models and agency and user cost data
- modification of the existing software for simultaneous runs of bridges and pavements
- revision of optimization procedures and incorporation of rate of return and other investment efficiency indicators for investments alternatives
- testing and preparation of documents of the software
- preparation of reports and revision of results
- preparation of training package.

This Case-Study was completed by end of July, 1993. At a latter stage, it is expected that the Case-Study would be integrated into the normal program of EDINU's training activities world-wide.

This Final Report shortly summarizes project preparation, project description and presents results of the Case-Study.

2 PROJECT DESCRIPTION

2.1 Background

Dr. Pedro Geraldes, from the Economic Development Institute of the World Bank, visited Helsinki from December 14 to 18, 1992 to, inter-alia, prepare with Finnish officials a proposed framework for co-operation between the Government of Finland and EDI's Infrastructure and Urban Development Division (EDINU). The signed Memorandum of Understanding (Annex 1) summarizes the consensus reached during the Mission's visit. The framework for co-operation would focus on a transport training program for senior sector managers and trainers from Republics of the Former Soviet Union, especially the Russian Federation and the Baltic countries, and from selected Central and Eastern European countries. It would cover a period of three years, during which a total of nine activities (each lasting for up to two weeks) would be delivered in Finland for the benefit of about 180 senior managers and some 45 professors from Universities and sector Research Institutes. The training program would address transport policy and operational issues, with emphasis on pricing and resource mobilization, economic and financial analysis of capital investment projects, environmental assessment, liberalization and private sector development, and business administration.

The above issues would be aggregated under three product lines of training activities. A key component of the training program is a Transport Management Development Program (TMDP). Participant managers would be identified among public sector officials already involved, or likely to be involved, in the preparation and appraisal of transport investments financed by multilateral financial institutions, including the World Bank. Program contents would cover fundamentals of transport economics; the project cycle with emphasis on the economic, financial and environmental analysis of projects; infrastructure management systems; logistics management and procurement.

The strategy to be followed in the preparation of training materials for the TMDP emphasizes the use of computer-aided decision-making techniques, based on economic benefit-cost concepts. Among these techniques are management systems allowing for a rational allocation of resources to the development and operation of infrastructure networks, including (but not limited to) paved roads and bridges. Such systems basically allow for an economic-based optimization of network expenditures, subject to budgetary constraints, based on the analysis of the trade-offs between user and infrastructure costs.

2.2 The Project

The primary aim of this assignment was to upgrade the Pavement Management System (PMS) and the Bridge Management System (BMS), currently being used by FinnRA, in order to prepare a Case-Study on Infrastructure Management System (IMS) capable of meeting TMDP's training requirements. As such, the main objectives of the assignment were to:

(i) incorporate the quantification of Vehicle Operating Costs (VOC) into the BMS, toward the analysis of trade-offs between user and infrastructure costs;
(ii) allow for the consideration of diverted traffic effects within the BMS, through the incorporation of a minimum-cost VOC algorithm;
(iii) consolidate the PMS with the BMS, so that they can be jointly optimized under one simultaneous constraints; and
(iv) prepare system and training documentation.

2.3 Organization and Administration

On behalf of the FinnRA, the project was supervised by Deputy Director, M.Sc., Raimo Tapio as a project manager. The other participants and their main duties were:

Project secretary Helena Ruottinen
Project secretary Katri Toivonen
Bridge Engineer Veijo Kuusinen, M.Sc.
Bridge Engineer Magnus Veijola, B.Sc.
Bridge Engineer Ari Kähkönen, M.Sc.
Mathematician Kimmo Tikka, M.Sc.
Bridge and Pavement Engineer Juha Äijö, M.Sc.
Economist and Statistician Vesa Männistö, M.Sc.
Economist and Statistician Antti Kanto, Ph.D.
Software Specialist Jukka Kujansuu, B.Sc.

This report was written by M.Sc. Vesa Männistö. On behalf of the World Bank the contact person was Senior Transport Engineer Carlos Alvarez from the Economic Development Institute.

2.4 Time Schedule and Expenses

The project was carried out within the planned time schedule (Appendix 3). The planned and actual number of person-months for the various tasks, as well as of the associated costs, is presented in Table 1. Testing of software (Task 7) is estimated to be concluded by the end of October, 1993.

Table 1. Expenses of the Project.

	Person-months		Costs (US$)	
	planned	**actual**	**planned**	**actual**
0. Administration	1	0.5	13 300	6 650
1. Bridge data preparation	5	3	66 500	39 900
2. Data base and data input	2	1	26 600	13 300
3. HIPS software changes	1	0.5	13 300	6 650
4. Economical indicators	2	1	26 600	13 300
5. Analysis of results	3	1	39 900	13 300
6. Recurrent (adp, trips, etc.)			13 800	6 900
7. Testing of software	0	1.5	-	20 000 (est.)
Total (US$)			**200 000**	**120 000**

3 INFRASTRUCTURE MANAGEMENT SYSTEM

The primary objective of this Study was to upgrade the Pavement Management System (PMS) and the Bridge Management System (BMS), currently being used by FinnRA, in order to prepare a Case-Study on Infrastructure Management System (IMS) capable of meeting TMDP's training requirements.

In the following, the basic features of the IMS are described.

3.1 Introduction

This chapter describes version 1.0 of the Infrastructure Management System (IMS), developed for the Finnish National Roads Administration by Statistical Computing Ltd, Inframan Ltd, and Viasys Ltd. IMS is a modified version of the Finnish network-level pavement management system, Highway Investment Programming System (HIPS) which was developed in co-operation with Cambridge Systematics, Inc., of Cambridge, Mass, USA. /1/

The purpose of the system is to optimize pavement and bridge rehabilitation policy and the allocation of funding among pavement and bridges. Currently operational for paved main roads and all bridges along main roads, the model covers general classes of rehabilitation actions from general patching to total reconstruction. Since it is a strict network-level model, the system analyzes road policies at an aggregate level, considering only sub-networks of roads or bridges.

Central to the optimization is a Markov dynamic program, which has been formulated as a linear programming problem for solution by off-the-shelf software. The dynamic programming categorizes pavements into 135 condition states and eight actions and bridges into 81 states and five actions, and represents deterioration as the probability of making transitions among all possible pairs of states over one year. An agency cost model estimates the cost of each possible action, and a user cost model evaluates the costs for road users in terms of travel time, fuel consumption, and vehicle depreciation, and for bridges in costs of diverted traffic due to weight restrictions.

In selecting optimal action for each possible state, the model tries to find a level of rehabilitation which minimizes societal costs, i.e. the sum of agency cost and road user costs. The program has both a long-term and a short-term component. In the long-term, the program tries to find an optimal steady-state condition to be attained in the future. In the short-term, the model tries to maximize progress each year in moving the current condition closer to the optimal condition distribution, subject to optional budget constraints.

Separate models are available for six models, three traffic volume classes for pavements and three for bridges. The Markov model and standard economical efficiency indicators optimize budget allocations within each of these six models, and a benefit-cost procedure optimizes the funding among them.

3.2 System Description

This system description is divided into two phases: in phase one, the basic features of HIPS, the ancestor system of IMS are presented. In phase two, the new economical features of IMS are discussed.

3.2.1 General Information

Figure 1 shows the structure of the IMS.

Two levels of analysis are provided to address the resource allocation policy questions of interest to the Ministry of Finance, Ministry of Transport, and Highway Administration. These are the:

- **Structure type** level, pavements or bridges. Each structure type has its own set of condition variables and actions to be modelled.

- **Volume class** level, which affects the rate of deterioration of pavements and bridges as well as the level of user costs associated with pavement condition and diverted traffic costs. Low-volume roads are those with average daily traffic below 1500, high-volume roads are those above 6000, and medium roads are those between. All modelling work occurs on the level of six permutations of structure type and volume class, termed the S/VC level.

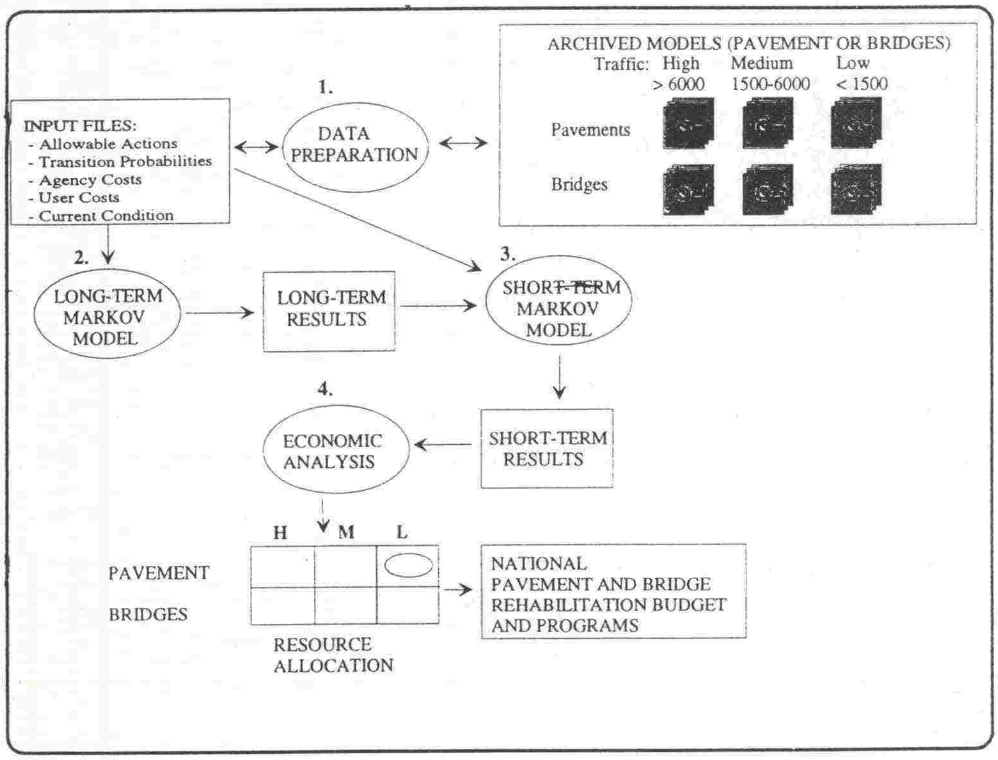


Figure 1. Structure of the IMS.

As in any far-sighted capital programming process, the highway administration should be concerned with the long-range goals which should be established for the highway network or bridge stock, and also with the steps needed to proceed from the current situation toward the long-range goals. This leads to the second important division within the IMS:

- **Long-term** model, which analyzes possible long-term goals and tries to find a future policy which minimizes social costs (the sum of user and agency costs) and is sustainable indefinitely in the future (Figure 2). The long-term model is not tied to the current condition of the network and imposes no requirements on which specific year it should be achieved.

- **Short-term** model, whose first priority is to find the quickest means of achieving the optimal level achieving the level of network condition; and whose second priority is to minimize the social costs incurred in the short-term period between now and the time when the long-term goals are achieved (Figure 2).

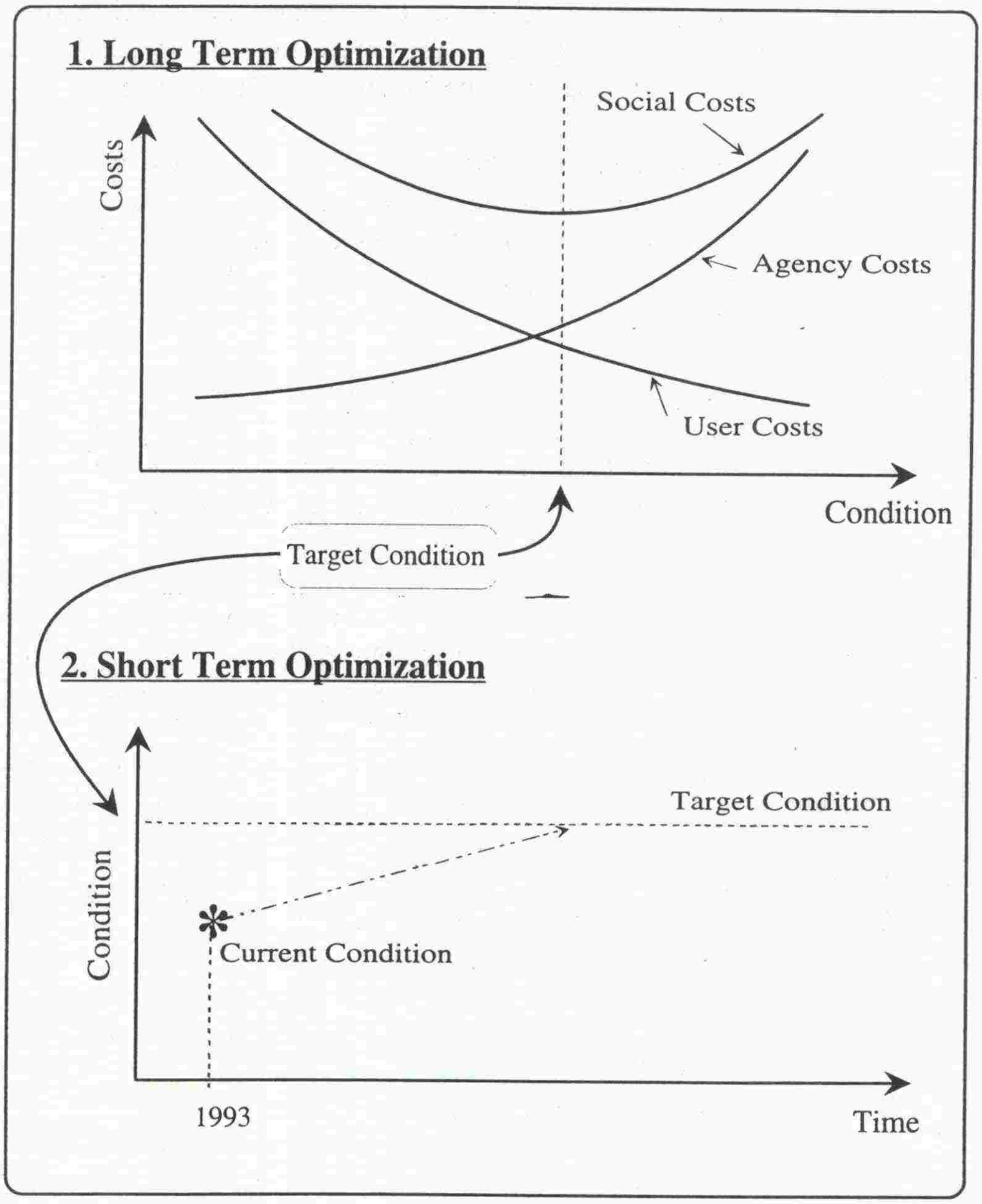


Figure 2. Optimization in IMS.

As figure 1 indicates, the flow of activities in using IMS starts at very abstract level and ends at a more concrete level. The long-term level defines goals broadly, this being some undetermined time in the future; this then proceeds to the short-term level, which is more concrete because it is explicitly tied to the current observed condition of the road or bridge network.

The ellipses numbered 1 to 4 in Figure 1 represent the major analytical features of the IMS, in the order in which they are normally used. Central to all of these features is the optimization model in processes 2 and 3, and the economical analysis and resource allocation within and between models in process 4. All these models include the following components:

- **Agency cost** model, giving the average costs for eight (five for bridges) general categories of maintenance and rehabilitation, from do-nothing to Total Reconstruction.

- **User cost** model, which quantifies in economic terms the increase in travel time, fuel consumption, and vehicle wear-and-tear associated with deteriorated road condition or additional detours associated with weight restrictions on bridges.

- **Deterioration model**, describing the process by which pavements and bridges deteriorate and thereby cause higher user costs to be incurred. Similarly, it also describes the improvements which can be expected after each of the general rehabilitation actions are applied.

- **Economical model**, describing the economical indicators and the process by which the decision-maker is able to compare various maintenance and rehabilitation strategies.

It is to be expected that, as the expenditure of agency cost increases, the resulting level of user costs will decline, as long as the available money is always used in the most cost-effective manner; also; as agency cost decrease, user costs go up. The economic optimization framework assumes that there is an intermediate point where social costs are minimized. Policy questions which are addressed in the framework are:

- What is the optimal level of expenditure on pavement rehabilitation on the nation-wide road and bridge network, and within selected subnetworks?

- At funding levels which do not minimize societal costs, what is the optimal allocation of funding among sub-networks, and what is the most cost-effective means of spending the available money: what is the best overall allocation among action types, and what actions should be applied to what kind of roads or bridges?

- To what extent do budget constraints increase the level of costs borne by road users, and what does this tell decision-makers about the importance to society of user costs relative to agency costs?

Many different modelling methodologies have been applied to these questions around the world. None of those methodologies has yet to be proven superior to the others. The methodology finally selected for this study was an adaptation of Markov dynamic programming. Attributes which made it attractive were:

- It describes the behaviour of pavements and bridges in a simple manner and fits well the decision-making process at strategic level, and is therefore suitable for the anticipated training.

- It explicitly recognizes the stochastic nature of pavement and bridge behaviour, and therefore expresses its conclusions in suitable form.

- The same approach is most obviously useful to other countries and other parts of infrastructure.

All activities involved in using the IMS are available from menu hierarchy.

3.2.2 Input Data and Organization of Models

Markov dynamic programming can be distinguished from other optimization approaches by several features:

- Problems are structured into multiple stages, which are solved one stage at a time.

- The range of possible outcomes of each stage is expressed as set of discrete states.

- The outcome of any stage depends stochastically on the outcome of the stage before it, i.e. Markov dynamic programming has one-step memory.

By applying a Markov model recursively over a series of stages, it is possible to predict probabilistically the outcome of any future state. Such a series of Markov predictions is called a Markov chain.

For the purposes of Infrastructure Management System, each stage is a description of the condition of the road or bridge network in a given year in terms of the distribution of roads or bridges among the set of possible states, combined with the choice of action taken in that one year. Figure 3 shows

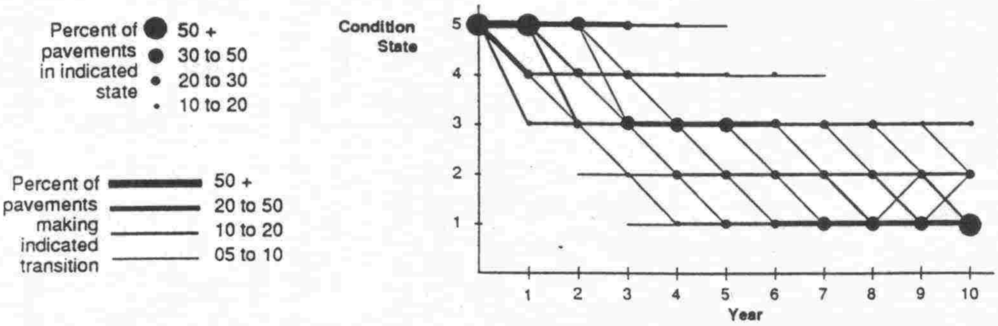


Figure 3. Markovian Deterioration.

how, in a system of 5 states, a Markov chain deterioration plays out for a pavement section starting in the highest state. As expected, the road ends up to the lowest state, but the path it uses get there may vary. Although this type of prediction may be of limited use in designing treatment for any particular road or bridge at project level, it is very useful for characterizing the whole network.

All together in the pavement models, there are 135 condition states and 8 action types, for a total of 1080 states describing each stage. Each state has associated with it an agency cost; a user cost; and a current condition distribution. The IMS software uses these input data to build linear programs to solve the long-term and short-term optimization problems using Hyperlindo-software. The mathematical descriptions of the linear programs are reviewed shortly in Chapter 3.2.3 and discussed thoroughly in the IMS User's Manual. The results from linear program are stored to the IMS-database and used for standard reporting and, also, transferred to additional EXCEL-based program package, which is used for economical analysis.

For defining an asphalt pavement's condition state, the following four major condition variables are used:

- Bearing capacity, abbreviated **K**, (5 classes, representing ranges of MN/m2)
- Defects, **V**, (cracking and patching, 3 classes, in square meters)
- Rut depth, **U**, (3 classes, in mm)
- Roughness, **T,** (3 classes, representing ranges of IRI)

Bearing capacity is considered to be the major factor inherent in a pavement which affects its subsequent deterioration, but defects and rutting also have this effect to a lesser degree. Defects, rutting, and roughness all have an effect on road user costs.

For bridges, there are 81 condition states:

- Superstructure, **S**, (3 classes; good, fair and poor)
- Substructure, **A**, (3 classes; good, fair and poor)
- Bearing capacity, **B**, (3 classes; good, fair and poor)
- Deck , **D**, (3 classes; good, fair and poor)

Bearing capacity of bridges is considered to be the major factor effecting to road user costs of bridges. Deterioration of single condition variables (e.g. deck) depends on other condition variables as well.

The maintenance districts have a larger number of standard rehabilitation procedures, but for the purposes of the Markov model they are condensed into several categories, which are for pavements:

- Do-nothing (routine maintenance)
- Rut patching
- General patching
- Planning
- Thin overlays
- Thick overlays
- Light reconstruction
- Heavy reconstruction

For bridges, the categories are:

- Do-nothing
- Minor improvements
- Strengthening
- Superstructure rehabilitation
- Reconstruction

All maintenance activity recommendations in the IMS are expressed in terms of these general categories.

3.2.3 Optimization

Optimization in IMS is executed at four steps:

1 Long-term optimization
2 Resource allocation among subnetworks
3 Short-term optimization
4 Optimization by economical indicators

The first three steps are executed inside the IMS-software. The fourth step, optimization and money allocation by economical indicators calculated from short-term results, is executed by separate EXCEL-procedures.

The following chapters will explain this optimization process briefly. More detailed information can be found from the IMS User's Manual /2/, which also includes basic reports of results used in this analysis.

3.2.3.1 Long-term Optimization

The long-term Markov model assumes a steady-state distribution of pavement or bridges among the condition states. This does not mean, that each road or bridge is always in the same condition, but it does mean that, in every year, the same overall distribution remains. It also means that the same fraction of roads and bridges undergo the same general action each year. This is all part of the requirement that the long-term program be not only optimal, but also sustainable, indefinitely.

Moreover, the long-term model is not in any way tied to the current condition distribution or current rehabilitation policy, but represents instead a goal that might be attained in the future. What makes this goal desirable is that it minimizes social costs. Thus, this goal is strongly recommended for the condition level to be used as an overall target.

The long-term program is calculated in the following manner as the objective function to be minimized is:

Social cost = C + U

where:

C is the agency cost = $\Sigma_a \Sigma_i W_{ai} C_{ai}$

U is the user cost = $\varnothing \Sigma_a \Sigma_i W_{ai} U_{ai}$

W_{ai} is the decision variable, the fraction of all pavement or bridges which are in state i and have action a applied to them.

U_{ai} is the user cost factor in thousands of dollars per km or unit bridge

C_{ai} is the agency cost factor in thousands of dollars per km or unit bridge

$\varnothing$ is the degree of user cost contribution to the objective function.

To prevent "leakage" from the system, and to give scale to the Wai decision variables, the first constraint is a definitional unity constraint:

$$\Sigma_a \Sigma_i W_{ai} = 1.$$

The most important element of the formulation is a constraint which combines the Markov model with the requirement of a steady state:

$$\Sigma_a \Sigma_i \; W_{ai} \, P_{aij} \;= \Sigma_a \, W_{aj} \qquad \text{for all j}$$

where:

P_{aij} is the transition probability of going to state j in year t+1, given state i in year t, when action a is applied in year t, which does not depend on t

Finally, the optional budget and condition constraints are included to the optimization. These constraints can either force the agency cost total to a certain level (either higher or lower than the social-cost minimization level) or define minimum and maximum allowable fractions to each class. The constraints are:

$$\text{BMIN} \leq C \leq \text{BMAX}$$

$$\text{CMIN}_c \;\leq \Sigma_{i \subset c} \, W_{ai} \;\leq \text{CMAX}_c \qquad \text{for all c}$$

where:

BMAX and BMIN are budget constraints, in dollars per km

CMAX_c and CMIN_c are fractions which represent the limits on the total fraction of pavements allowed to be in each class.

Both user cost contribution ∅ and budget constraints can be varied in the parametric analysis in order to gain information on the sensitivity of results to these variables.

3.2.3.2 Allocation Among Submodels

By setting up and running a long-term Markov model for each three pavement and three bridge sub-networks, the analyst can determine the social cost minimizing rehabilitation policy for each sub-network. If the sum of these policies is not within the realistic range that the Administration can expect, the question is, what constraint should be applied to each sub-network or, in other words, how should funding be allocated among them?

There are two procedures to solve this problem in IMS. This first one is based on the assumption that the national funding level for pavement and/or bridge rehabilitation represents the relative value which society places on user costs opposed to agency costs. IMS conducts an analysis by using a variation of the incremental benefit-cost technique. Between any two parametric step (meaning different budget limits for a model), the quotient of change in user cost divided by change in agency cost is called **shadow price**.

A criterion for an economically-efficient allocation of resources among the six sub-networks, at funding levels that do no minimize social costs, is that the shadow price is equalized among the sub-networks. In practice, the user sets up a very broad parametric analysis for each sub-network, including the highest and lowest conceivable budget levels, to gain the allocation report where one can choose an admissible budget level.

This procedure is based only on the long-term analysis of pavements and bridges. Thus, the results gained from it are not strictly optimal, because it does not take the current condition distributions into account. This type of optimization is done under separate EXCEL-programs (see Chapter 3.2.4).

3.2.3.3 Short-term Optimization

All long-term analysis focuses on a scenario which may take place at an undetermined time in the future. What is needed next is a capability to model the steps required to bring the existing pavement and bridge networks to the optimal condition level, determined by the long-term program. This is done by the short-term Markov model.

The purpose of the short-term model is to find the shortest practical means of achieving the long-term condition distribution, by obeying the optional yearly budget constraints simultaneously. The approach chosen is to model each year separately in the short-term, with the objective function trying to minimize the deviation between the condition distribution and the optimal condition distribution. In other words, the short-term model tries to maximize the amount of progress made each year. Mathematically, the objective function is:

$$\mathrm{MIN}[\Sigma_c\,(K_cX_c + K_cY_c) + \alpha\,\Sigma_a\, W_a(|L_a - S_a|)]$$

where:

X_c is the amount by which the fraction of pavements in class c is above the long-term optimal fraction

Y_c is the amount by which the fraction of pavements in class c is below the long-term optimal fraction

K_c is the average social cost in marks per kilometer or unit bridge of class c. It is computed from the long-term steady state condition distribution and the unit agency and user cost by:

$$K_c = \Sigma_{i \subset c}\,\Sigma_a\, W_{Tai}\,(C_{ai} + U_{ai}) / \Sigma_{i \subset c}\,\Sigma_a\, W_{Tai}$$

where W_{tai} is the long-term fraction of pavements or bridges in state i with action a, U_{ai} is the user cost factor per km (or unit bridge), and C_{ai} is the agency cost factor in marks per km (or unit bridge).

α weight factor

L_a is the long-term fraction in class a

S_a is the current condition fraction in class a.

The weights, K_c, placed on the objective function variables assure that the classes having highest social costs receive the highest priority. Using the X_c and Y_c variables allow the Markov constraints to be expressed in terms of the long-term condition distribution, as follows:

$$\Sigma_{j \subset c} \Sigma_c \Sigma_i W_{ai} P_{aij} - X_c + Y_c = \varepsilon_c \qquad \text{for all c}$$

where:

P_{aij} is the transition probability of going to state j in year t+1, give state i in year t, when action is applied in year t

ε_c is the short-term ultimate distribution among condition classes, usually computed as a summation of the long-term state distribution.

Since this formulation is run separately for each year, a constraint is needed for initial condition distribution at the beginning of the year. In the first year, this constraint is known distribution which has been measured in the field. In the subsequent years, the constraint is the distribution output from the preceding year's solution.

The short-term model also has optional budget constraints, which are identical to those used in the long-term model. Moreover, a report is provided in the IMS to allocate a fixed short-term budget level, according to the amount of improvement needed to maintain the long-term distribution and according to the amount of improvement needed to reach the long-term solution. Normally, the analyst's judgement and non-economic considerations also play a major role in setting the short-term budget levels.

3.2.4 Economic Analysis

The other chief aim of this study has been the incorporation of additional economic indicators into the analysis. These new indicators are calculated by separate EXCEL-procedures. The theory and use of this analysis is presented in this chapter, based on reference /3/.

3.2.4.1 Basic Concepts

In order to compare policy alternatives some measures are needed which describe the benefits from the policy or the investment.

Usually, money savings are not the only goal by which the value of the investment is to be considered. Alternative goals, such as time or risk have also be taken into account. Because of this multi-criteria decision situation, there are several alternative measures of the value. They may lead to different decisions although usually the results are similar.

The **net present value (NPV)** of an investment is the discounted gain from the investment. The gain is calculated as the difference of the user cost of the policy minus the user cost of reference policy. As the reference policy the do-nothing policy is normally used where only the ultimate investments are made. We denote this difference as cost reduction (CR). It is calculated for successive years ahead in the investment period, In the IMS the investment period is rather arbitrarily taken as T=8 (A longer period could also easily be used.)

When a **discount rate, r** is used the present value of cost reduction in year t is the discounted social cost reduction (SCR), i.e.

$$SCR(t) = CR(t)/(1+r)^t$$

where t = 1,...,8.

Clearly, SCR(t) depends on the discount rate used. SCR(t) can be considered as the amount of money to be saved in a bank at t=0 if one wants to compensate the extra cost SCR(t) at year t. We may thus think SCR(t) as the sum of agency cost at year t and costs caused to users in year t if the investment is not carried out. The net present value (NPV) of the investment is the sum of the yearly present values:

$$NPV = \Sigma_t \ SCR(t) = \Sigma_t \ CR(t)/(1+r)^t$$

Net present value depends heavily on r and it is a decreasing function of r. It is regarded as the total gain from the investment in terms of lowered user costs, when the interest is taken into account.

When r is large enough, there is a point where NPV = 0. This corresponds to the value of r for which discounted user cost reduction equals discounted agency costs. This value of r is called **internal rate of return (IRR)**. It thus denotes the largest discount rate with which the investment still is profitable. It may occur that NPV < 0 for all r > 0, which means that the investment will be nonprofitable in every circumstances. Usually this means that agency costs are so high that they will not be paid back during the analysis period in terms of decreased user costs. On the other hand it may happen that NPV is always positive, which means that the investment is profitable no matter how large the discount rate is. Such situations are rare.

If the discount rate is high, it may become more profitable not to make the investment and pay users later in cash or tax reduction etc. On the other hand, if the rate of return is small, it can be profitable to take a loan from the bank and make the investment. This loan is then paid back by the lowered user costs.

In addition to NPV and IRR, other measures can be used as well such as **first year benefit**, which simply is CR(1) or time to **break-even (TBE)**, which equals the time t(0) by which the investment is paid back by the lowered user costs.

User cost reduction (UCR) in turn means the (discounted) cost reduction of users if the investment is made. It simply is the (discounted) difference of social and agency costs.

One simple way to evaluate a policy is to calculate its average gain per dollar invested. It may be, however, misleading, because when the investment is small its gain per dollar is usually higher than for larger investments. In economic theory this phenomenon is known as the law of decreasing marginal revenue. A better way is to compare two similar policies, one larger and the other smaller. If the difference between their budgets and the difference between their user cost reductions are calculated, we may by division calculate what was the gain from the last dollars invested in the larger budget. This is called the **marginal revenue of the investment (MR)**. With no budget constraint one should usually go to larger and larger budgets until investment increase becomes larger than the gain. Usually, however, a budget constraint exists. In such case marginal revenue can be used in allocation of money between different models. If some investments should be deferred, cancelled or decreased, one should choose the model with smallest marginal revenue, i.e. the model where gain from last dollar invested is smallest.

3.2.4.2 Comparison of Alternative Measures

Though being simple the measures explained earlier suffer from some draw-backs. The most serious comes with IRR. In some cases it may lead to wrong decisions. These occasions are, however, rare in road-keeping. Suppose, for example, that we are building a nuclear power plant, which has to be torn down after forty years. If the discount rate is too high, the investment will not be profitable. However, if the interest rate is small enough the price to be paid for pulling the plant down after use will be so high when discounted to present that the investment will also be non-profitable. In such case NPV is not a decreasing function of r. Another weakness of IRR is that an investment with larger IRR may not have larger NPV for reasonable values of r. IRR, however, serves as a good measure when deciding whether the investment is profitable or not at all.

The draw-back in NPV is that r is usually unknown. Anyway, reasonable estimates usually exist. First year benefit is easy and quick to calculate, but it tells only little on the total value of the investment. The same holds also for TBE, but it is a useful measure, if time is the most critical factor in decision making.

3.2.4.3 The Contents of the Economic Analysis Program

The Economic Analysis package consists of three EXCEL 4.0 worksheets:

- **ECON**
- **GAIN**
- **MODEL**

The most profitable policy for each model is calculated in **ECON**. The module **GAIN** compares policies with a chosen discount rate. The last program, **MODEL**, is used in allocation of monies between models.

These worksheet programs use IMS Short-term results as input data. The short-term results are firstly stored from IMS into MODELaaa.ECO-file, where aaa is the model identification. From these ASCII-files, cost data is retrieved to an EXCEL-database, named DATAB.XLS.

Module ECON

The first program ECON does the calculations needed in the choice of the most profitable policy. Note that the policy chosen depends on the rate of return and the preferences of the decision maker. One decision maker may want a large eight year payoff; another in turn a quick payoff - break-even in three years, say. Because the rate of return in the future is unknown, it is useful to consider several alternative rates of returns in order to look how sensitive the investment policies are to fluctuations in the rate of return.

The ECON-worksheet is shown in Figure 4. The first row contains the name of the model (Pavement High,..., Bridge Low). It is also possible to rename the session by overwriting green cells. The second row contains the names of the policies (max 1+5, do nothing and five other policies, usually different budget constraints) to be considered. First column (A) contains the results from the reference policy in terms of social costs. Columns B,C,D,E and F contain the results from the other policies. The reference policy should usually be the do-nothing policy but other reference policies can be used as well. The policies are denoted by colours red, green, blue, yellow and pink, respectively. If one of these policies is changed, the tables and figures are updated immediately.

The first result figure gives social costs from each policy except the reference policy. If the reference policy is also wanted in this figure, then column B of the data table should also contain the reference policy, i.e. rows A and B should equal.

If the curve is decreasing, the row condition is improving in eight years, and vice versa.

IRR (Internal Rate of Return) is the largest discount rate for which the investment is profitable. If IRR is small, the investment is nonprofitable or sensible to fluctuations in the market discount rate. If the investment is made using loans, IRR should always be larger than the interest rate of the loan. On the other hand, if two policies both have a large IRR, the decision between these two should not be based on IRR. IRR should only be used in discarding nonprofitable policies.

The second figure shows the gain of each policy when subtracted from the reference policy. Normally there is a loss in one or two first years where the investments are started but become positive later.

The total gain from the policies can be compared using **NPV (Net Present Value)**, which is the discounted value of the investment during the eight year investment period. As a rule of thumb, the policy which has the highest NPV (if positive) is the most profitable.

To calculate the NPV, the discount rate (in percent) is written in the cell A32. It can be changed if necessary.

Module GAIN

The second program GAIN compares policies with a chosen discount rate in terms of profit per dollar. The GAIN-worksheet is shown in Figure 5.

Data acquisition is carried out as in the case of the program ECON. Now, however, both social costs and agency costs are transferred from the database. In order to avoid confusion they should be transferred simultaneously.

The discount rate is written in the cell A22. It can be changed when necessary.

First result table gives user cost reduction, agency cost reduction and social cost reduction during the total eight year period. In the case where social cost reduction is negative, agency costs are larger than the gain of the user and the investment is therefore unprofitable.

The first figure gives social cost reduction as a function of agency cost in eight years for all alternatives used in the analysis.

Second table gives first year agency cost (per kilometer) for each policy and marginal social cost reduction for each policy. The marginal cost is the gain from the last dollar invested in the policy.

The second figure gives marginal gain as a function of first years agency cost.

Module MODEL

The third program MODEL is used in allocation of monies between models. The data is already in the program so that no data input is needed. The worksheet is shown in Figure 6.

The sheet consists of the results of the GAIN program for three pavement models and three bridge models. For each model data consists of total unit agency costs (per kilometer or unit bridge) and marginal cost reduction (user gain from the last dollar invested) with three policies. The central column is the one with which calculations are carried out. On left and right side are two alternative policies. The yellow cell gives the total agency cost (i.e. the total budget of the model). It is the unit agency cost multiplied by the volume (kilometres or unit bridges). The yellow cell at the bottom gives the total budget of all models, its marginal cost reduction together with its average cost reduction, i.e. the average cost reduction for each dollar invested.

In the program it is possible to manually allocate money between models by increasing or decreasing budget of models. The procedure is as follows:

1 Select one of the green or yellow cells in some model.
2 Press either the + or - buttons in the bottom of the sheet.

Go on increasing and decreasing money until an admissible solution is found.

3.2.5 Results of the IMS

There are usually numerous results which management information systems provide for the users and the decision-makers. The following short list summarizes the most important outputs drawn from the Infrastructure Management System.

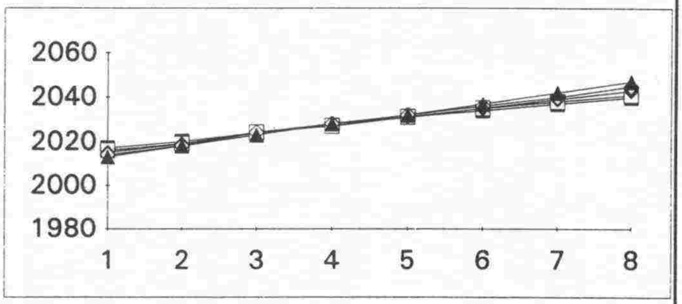
- current condition distributions of sub-networks
- optimal condition distributions of sub-networks
- optimal yearly budget for a sub-network
- resource allocation between sub-networks
- rate of returns and net present values of different policies
- 8-year rehabilitation recommendations
- condition forecasts

Examples of these results are included to the training package and to the IMS User's Manual.

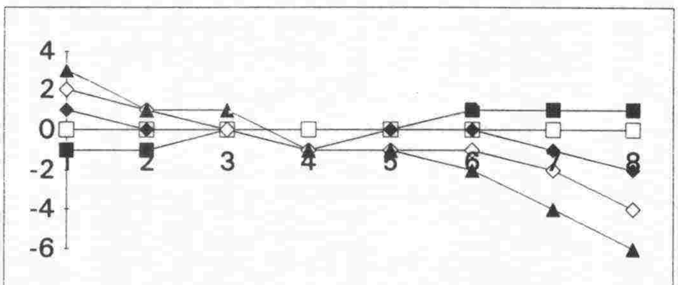
IMS Economic Analysis

MODULE ECON

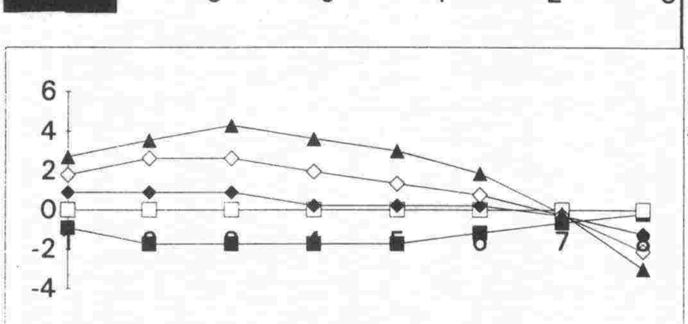
[redacted]					
pm12	pm13	pm12	pm11	pm10	pm9
2016	2017	2016	2015	2014	2013
2019	2020	2019	2019	2018	2018
2024	2024	2024	2024	2024	2023
2027	2027	2027	2028	2028	2028
2031	2031	2031	2031	2032	2032
2035	2034	2035	2035	2036	2037
2038	2037	2038	2039	2040	2042
2041	2040	2041	2043	2045	2047



[redacted]	8%	0%	0%	0%	0%



[redacted]	0	0	-1	-2	-3



Data aquisition

1. Select database file from Window menu.
2. In the data base select policy/policies .
3. Click right button. Select copy.
4. Select ECON.WLS from the Window menu.
5. Select cell A2-F2. (A2 for the reference policy)
6. Click right button. Select paste.
7. Name data set in green cell A1.

Order of colors is red, green, blue, yellow, pink.

The first figure gives social costs from each policy excepting the reference policy.

IRR gives the largest discount rate for which the investment is profitable.

The second figure shows the gain when substracted from the reference policy.

Calculation of the Net Present Value

Write the discount rate in the red cell A32. It can be changed when necessary.

NPV gives the net value of each policy with given discount rate.

The third figure gives the year, when each policy becomes profitable when compared to the reference policy.

Figure 4. Module ECON.

IMS Economic Analysis **MODULE GAIN**

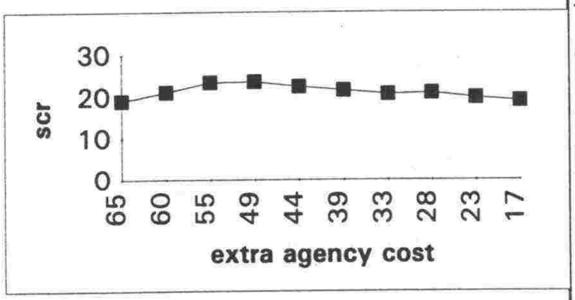
[redacted]

pm0	pm15	pm14	pm13	pm12	pm11
2005	2019	2018	2017	2016	2015
2013	2022	2020	2020	2019	2019
2021	2025	2025	2024	2024	2024
2030	2028	2028	2027	2027	2028
2040	2031	2031	2031	2031	2031
2050	2034	2034	2034	2035	2035
2060	2037	2037	2037	2038	2039
2070	2039	2040	2040	2041	2043

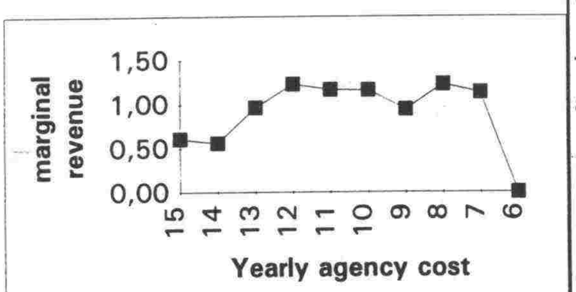
[redacted]

pm0	pm15	pm14	pm13	pm12	pm11
1	15	14	13	12	11
2	15	14	13	12	11
2	15	14	13	12	11
3	15	14	13	12	11
3	15	14	13	12	11
4	15	14	13	12	11
4	15	14	13	12	11
5	15	14	13	12	11

[redacted]	65	60	55	49	44
	19	21	24	24	22



[redacted]	15	14	13	12	11
	0,61	0,56	0,96	1,23	1,17



Data acquisition

1. Select database file from Window menu.
2. In the database select policy/policies .
3. Click right button. Select copy.
4. Select GAIN.WLS from the Window menu.
5. Select cells A2-F2. (A2 for reference policy)
6. Click right button. Select paste.
7. Name data set in cell A1.

Order of colors is red, green, blue, yellow and pink.

Ten different policies may be compared though only five are shown on the monitor.

Social and agency costs can be read also simultaneously.

Setting the discount rate
Write the discount rate in the red cell A22. It can be changed when necessary.

Table gives user cost , agency cost and social cost reduction for each policy.

The first figure gives social cost reduction as a function of agency cost in eight years.

Table gives first year agency cost for each policy and marginal social cost reduction (gain from the last dollar invested).

The second figure gives marginal gain as a function of first years agency cost.

Figure 5. Module GAIN.

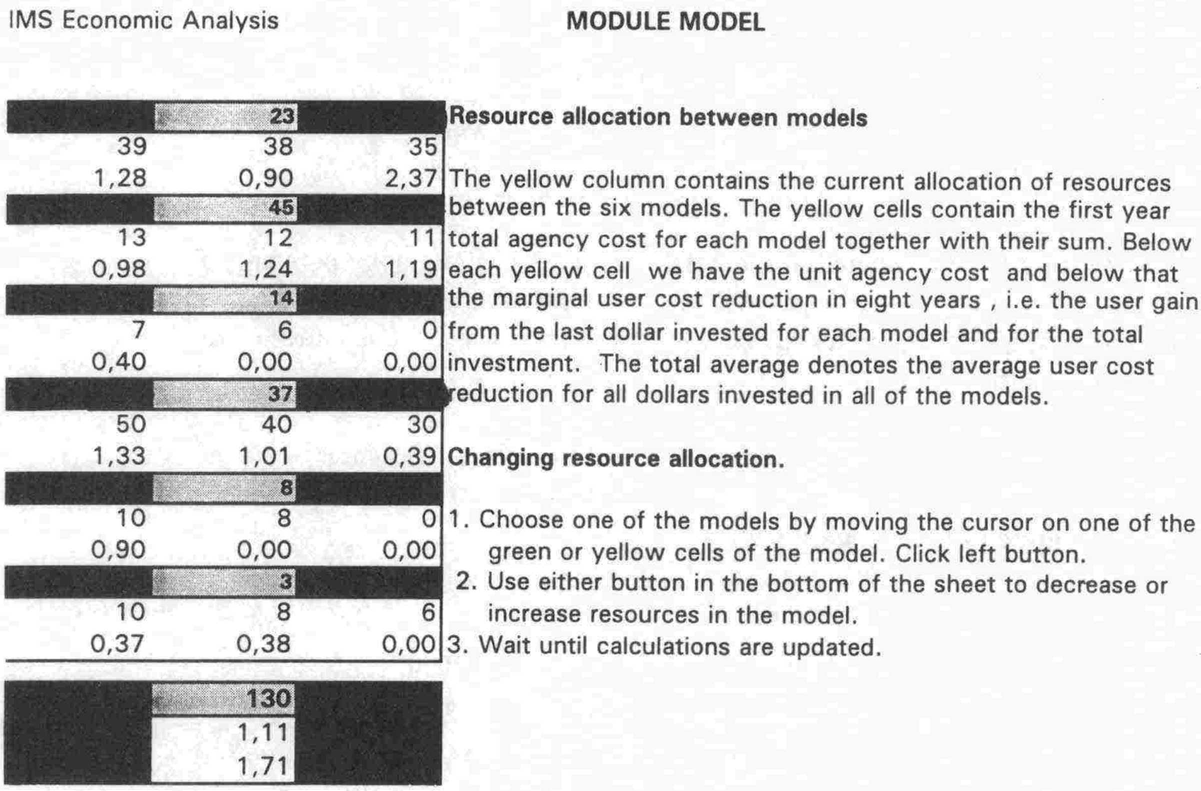


Figure 6. Module MODEL.

3.3 Models and Input Data

In this chapter, the basic input data and models of pavements and bridges for this first case-study are presented. Pavement data set is based on the data used in HIPS /4/, bridge data set was developed mainly by the project group.

3.3.1 Pavement Data

The pavement data set for this case-example consists of main roads of Finland, comprising altogether about 12 000 km's of paved roads. In the original version of IMS, i.e. in HIPS, the paved road network is divided into two pavement types, asphalt concrete and oil gravel (cold-mix asphalt). For IMS purposes, these pavement types are combined into one type. The length of this network divided into traffic volume groups is as follows:

	South	North	Total
Asphalt	4 645	5 006	9 651
Oil gravel	12	2 255	2 267
Total	4 657	7 261	11 918

The total kilometres above include two-lane roads twice.

The average daily traffic distribution is as follows:

	ADT > 6000	1500 - 6000	< 1500
Kilometres	2 179	5 852	3 887
Percent	18 %	49 %	33 %

The fraction of roads located at the northern region is about sixty percent, of oil gravel roads almost 100 percent. This implied to the decision, that the deterioration and cost models to be used were basically the ones developed for the northern region.

The class limits of condition variables used in IMS are the following:

Bearing capacity (MN/square meter):

class	ADT < 1500	1500 - 6000	> 6000
0	> 230	> 260	> 330
1	201 - 230	241 - 260	311 - 330
2	171 - 200	221 - 240	251 - 310
3	141 - 170	201 - 220	211 - 250
4	< 140	< 200	< 210

Roughness (IRI, in mm/m):

class 0	1	2
< 2.0	2.0 - 3.5	> 3.5

Rutting (in mm):

class 0	1	2
< 13 mm	13 - 20 mm	> 20 mm

Defects (in square meters/100 m):

class 0	1	2
< 15 sq.m.	15 - 58 sq.m	> 58 sq.m.

3.3.1.1 Current Condition Distribution

The current condition distribution of pavements is described by 135 different condition states (5*3*3*3 = 135). This 135-classification is the basic structure of IMS and all condition and cost data is defined according to this classification. The following table shows an example of this distribution retrieved from the FinnRA's road condition register KURRE as in the 1st of January 1993. In this table, bearing capacity and roughness are row variables; rutting and defects are column variables.

For example, 34.58 percent of roads are in excellent condition (the cell in the left upper corner).

Table 2. Current condition of high traffic volume roads (in 1/10000's).

	UV								
KT	**00**	**01**	**02**	**10**	**11**	**12**	**20**	**21**	**22**
00	3 458	30	1	33	2	2	1	1	1
01	3 279	73	6	107	9	1	25	1	1
02	54	5	1	3	3	1	62	23	1
10	145	3	1	1	1	1	1	1	1
11	398	14	3	81	4	1	1	1	1
12	10	1	1	1	1	1	1	1	1
20	198	1	1	4	1	1	1	1	1
21	411	24	1	9	1	1	28	1	1
22	23	3	1	4	3	3	1	5	1
30	66	12	1	9	1	1	2	1	1
31	221	57	2	25	2	1	6	1	1
32	6	1	1	4	1	1	1	19	1
40	503	1	1	1	1	1	1	1	1
41	382	1	1	3	1	1	7	1	1
42	7	2	1	1	1	1	9	32	1

3.3.1.2 Maintenance Actions

The maintenance and rehabilitation actions are grouped from the numerous ones used in Finland into eight categories according to their costs and effects. These are as follows:

Number	Description	Cost per km (in 1000 FIM)
0	Do nothing	1 - 23
1	Rut patching	86
2	Patching	34 - 57
3	Planing	90 - 136
4	Thin overlay	181 - 256
5	Thick overlay	212 - 282
6	Light reconstruction	470 - 1112
7	Heavy reconstruction	681 - 1446

The effects of these maintenance and rehabilitation actions to road condition is described in FinnRA's reports. The following example shows how does the action #7 (heavy reconstruction) effect to rutting:

	year	t+1		
year		**0**	**1**	**2**
t	**0**	100	0	0
	1	100	0	0
	2	100	0	0

Thus, all the roads will be in the best rutting class a year after action 7, heavy reconstruction, is applied.

3.3.1.3 Road User Costs

Road user costs are defined in the FinnRAs annual road user costs report /5/. All the parameters used in calculations are included into Appendix one. The following text describes the basic features of user cost calculations.

The general user cost (UC) model is of the form

UC = accident cost + vehicle operating cost + travel time cost.

Accident costs include the cost from fatal and other accidents; vehicle operation costs include fuel consumption, tires, maintenance, depreciation, and capital cost; and travel time costs include time costs for the driver and passengers.

For the user cost calculation for the Finnish network-level pavement management, an EXCEL-procedure has been developed. The current user cost model includes the following numerical cost variables for cars and trucks:

- Average daily traffic
- Vehicle operating cost (p/unit/vehicle)
- Travel time cost (p/unit/vehicle.)
- The accident rate
- Change of accident rate due to condition variables T, U and V (%)
- The average vehicle target speed
- Change of speed due to T, U and V (%)
- Change of vehicle operating cost due to T, U and V (%)
- Additional cost of action per day per vehicle; detour due to the action (time + vehicle + speed reduction) (p/unit/vehicle)
- Length of maintenance action (days)

In the best road condition class, KTUV (0000), the user cost per one kilometer is 6531 kmk/year, if no maintenance action except routine maintenance is executed.

The extra costs which maintenance actions cause to the user costs are summarized in the following table:

Action	UC min KTUV (0000)			UC max KTUV (4222)		
	H	**M**	**L**	**H**	**M**	**L**
0 Do nothing	6 531	1 976	713	7 543	2 290	828
1 Rut patching	6 535	1 977	714	7 547	2 291	829
2 Patching	6 535	1 977	714	7 547	2 291	829
3 Planing	6 539	1 978	714	7 551	2 292	829
4 Thin overlay	6 539	1 978	714	7 551	2 292	829
5 Thick overlay	6 560	1 983	716	7 572	2 298	831
6 Light reconstruction	6 987	2 099	762	7 999	2 414	877
7 Heavy reconstruction	6 987	2 116	762	7 999	2 430	877

The negative effects of rehabilitation are traffic delays, comprising about 7 percent of the normal user costs, at maximum.

Effects of Condition Variables to User Costs

The condition variable bearing capacity has no straightforward effect on user costs. It's effect comes via acceleration of surface condition deterioration.

The effect of roughness into road user costs is highest, about 7 percents between the best and worst classes. Rutting effects about 5 percent and defects about 3 percent. The concurrent effect of all condition variables at the same time increase user costs about 16 percent.

3.3.1.4 Deterioration Models

Road deterioration is described using Markov process. Deterioration models have been estimated using real measurement data from the 3000 km sample road network in Finland /6/. The current models are based on measurements executed at 1989 and 1990.

The transition probability models for each condition variable (K, T, U and V) are in the following general form:

Year		t + 1		
	i/j	0	1	2
	0	p_{00}	p_{01}	p_{02}
t	1	0	p_{11}	p_{12}
	2	0	0	1

where:

t year t
t + 1 next year
0, 1, 2 conditon classification
i condition class index for year t
j condition class index for year t + 1
p_{ij} probability to make the transition to condition class j when the condition class in year t has been i

The basic assumption is that with no repair actions the road condition cannot improve, e.g. p_{10}, p_{20} and p_{21} are structurally set to zero.

The transition probabilities p_{01} for each condition variable have been estimated using logistic regression analysis:

$$\log[p/(1-p)] = \beta_0 + \beta_1 X_1 + \ldots + \beta_k X_k$$

where:

p transition probability (p_{01})
$X_1,\ldots,X_k$ independent variables (other conditon variables or traffic volume class
$\beta_0,\ldots,\beta_k$ unknown parameters

In the case of p00, p01 and p02, a better model is ordinal logistic regression model

$$\log[\Theta_j/(1-\Theta_j)] = \delta_j - (\beta_1 X_1 + \ldots + \beta_k X_k)$$

where:

j	1 or 2
Θ_1	p_{01}
Θ_2	$p_{01} + p_{02}$
X_i	independent variables
δ_i, β_i	unknown parameters

In the estimation of transition probabilities for a condition variable, the relevant candidates for independent variables are other condition variables (e.g. in modelling of defects, the explanatory variables can be bearing capacity class K; rutting class U; and roughness class T) and average daily traffic class ADT.

The following models are used in the IMS. Detailed information of these models can be found from the research work conducted. It is to be noted that logistic regression models use classification 1,2,3 instead of 0,1,2.

Bearing Capacity

Bearing capacity models were estimated from the road data bank data of Finland in 1988. The transition probabilities are shown separately for each ADT class in the next three matrices.

ADT > 6000:

t / t+1	**0**	**1**	**2**	**3**	**4**
0	0.992	0.008	0	0	0
1	0	0.934	0.066	0	0
2	0	0	0.981	0.019	0
3	0	0	0	0.969	0.031
4	0	0	0	0	1

ADT 1500 - 6000:

t / t+1	**0**	**1**	**2**	**3**	**4**
0	0.998	0.002	0	0	0
1	0	0.993	0.073	0	0
2	0	0	0.995	0.048	0
3	0	0	0	0.993	0.065
4	0	0	0	0	1

ADT < 1500:

t / t+1	0	1	2	3	4
0	0.9996	0.0004	0	0	0
1	0	0.9995	0.0005	0	0
2	0	0	0.9996	0.0004	0
3	0	0	0	0.9996	0.0004
4	0	0	0	0	1

Roughness

The following models are used:

$$p(T_{t+1}= 1 \mid T_t = 1) = 0.996 * \exp(tp1)/(1+\exp(tp1))$$

$$p(T_{t+1}= 2 \mid T_t = 1) = 1- p(T_{t+1} <> 2 \mid T_t = 1)$$

$$p(T_{t+1}= 3 \mid T_t = 1) = 0.0034$$

$$p(T_{t+1}= 2 \mid T_t = 2) = \exp(tp2)/(1+\exp(tp2))$$

$$p(T_{t+1}= 3 \mid T_t = 2) = 1- p(T_{t+1}= 2 \mid T_t = 2)$$

where:

$$tp1 = 0.902 - 0.158*KVL - 0.297*K_t - 0.380*V_t$$

$$tp2 = 5.13 - 0.255*K_t - 0.718*V_t$$

KVL	average daily traffic class (1 = high, 2 = medium, 3 = low)
K_t	bearing capacity class (1 = excellent, ..., 5 = poor)
V_t	defect class at year t (1 = excellent, 2 = good, 3 = poor)
p()	probability
T_t	roughness class at year t (1 = excellent, 2 = good, 3 = poor)
exp()	exponent function

Defects

The following models are used:

$$p(V_{t+1}= 1 \mid V_t = 1) = \exp(vp1)/(1+\exp(vp1))$$

$$p(V_{t+1}= 2 \mid V_t = 1) = \exp(vp2)/(1+\exp(vp2)) - p(V_{t+1}= 1 \mid V_t = 1)$$

$$p(V_{t+1}= 3 \mid V_t = 1) = 1- p(V_{t+1}= 1 \mid V_t = 1) - p(V_{t+1}= 2 \mid V_t = 1)$$

$$p(V_{t+1}= 2 \mid V_t = 2) = \exp(vp3)/(1+\exp(vp3))$$

$$p(V_{t+1}= 3 \mid V_t = 2) = 1- p(V_{t+1}= 2 \mid V_t = 2)$$

where:

$$vp1 = 4.04 - 0.634*KVL - 0.294*K_t - 0.287*T_t$$

$$vp2 = 6.17 - 0.634*KVL - 0.294*K_t - 0.287*T_t$$

$$vp3 = 3.54 - 0.405*KVL - 0.594*T_t$$

KVL average daily traffic class (1 = high, 2 = medium, 3 = low)
K_t bearing capacity class (1 = excellent, ..., 5 = poor)
V_t defect class at year t (1 = excellent, 2 = good, 3 = poor)
p() probability
T_t roughness class at year t (1 = excellent, 2 = good, 3 = poor)

Rutting

The following models are used:

$$p(U_{t+1}= 2 \mid U_t = 1) = \exp(up1)/(1+\exp(up1))$$

$$p(U_{t+1}= 1 \mid U_t = 1) = 1- p(U_{t+1}= 2 \mid U_t = 1)$$

$$p(U_{t+1}= 3 \mid U_t = 1) = 0$$

$$p(U_{t+1}= 3 \mid U_t = 2) = \exp(up2)/(1+\exp(up2))$$

where:

$$up1 = -9.46 + 0.891*\log(KVL) - 0.0017*K_t - 0.048*V_t$$

$$up2 = -17.4 + 1.96*\log(KVL) - 0.00354*K_t$$

KVL average daily traffic class (1 = high, 2 = medium, 3 = low)
K_t bearing capacity class (1 = excellent, ..., 5 = poor)
V_t defect class at year t (1 = excellent, 2 = good, 3 = poor)
T_t roughness class at year t (1 = excellent, 2 = good, 3 = poor)
U_t rutting class at year t (1 = excellent, 2 = good, 3 = poor)

3.3.1.5 Models for Effect of Maintenance and Rehabilitation

Due to the lack of real measurement data in late 1980's, these models were formulated using Delphi-questionnaire /7/.

The basic assumption has been that routine maintenance does not improve road condition. Other maintenance action improve road condition either of one or several variables. The following example shows how does the thick overlay improve the road condition according to all condition variables.

Example. Effect of thick overlay (action #5), in high traffic volume roads

The following table shows the effect of thick overlay to all condition variables.

t + 1

K

t	px0	px1	px2	px3	px4
p0x	1	0	0	0	0
p1x	1	0	0	0	0
p2x	0.5	0.5	0	0	0
p3x	0	0	0.9	0.1	0
p4x	0	0	0	0.9	0.1

T

t	px0	px1	px2
p0x	0.9	0.1	0
p1x	0.7	0.3	0
p2x	0.6	0.4	0

U

t	px0	px1	px2
p0x	1	0	0
p1x	0.95	0	0.05
p2x	0.9	0.1	0

V

t	px0	px1	px2
p0x	1	0	0
p1x	0.95	0	0.05
p2x	0.95	0.03	0.02

3.3.1.6 Allowable States and Actions

The basic assumption is that Do-nothing is allowed to every condition state. This enables the examination of very strict strategies, including very low budget limits. Rut patching and patching are allowed mainly to the situation where there are no problems with the bearing capacity. Thin and thick overlays are the basic actions and are, thus, allowed to almost all states. Finally, both reconstruction actions are allowed when bearing capacity is already rather low.

3.3.2 Bridge Data

In this chapter, the current bridge models and data set used in analysis is presented. This basic data consists of concrete bridges of the main road network in Finland. The data is prepared by the project group according to the basic definitions of the Finnish Bridge Management System /8/.

As an introduction, figure 7 shows the major structural parts of a typical concrete bridge.

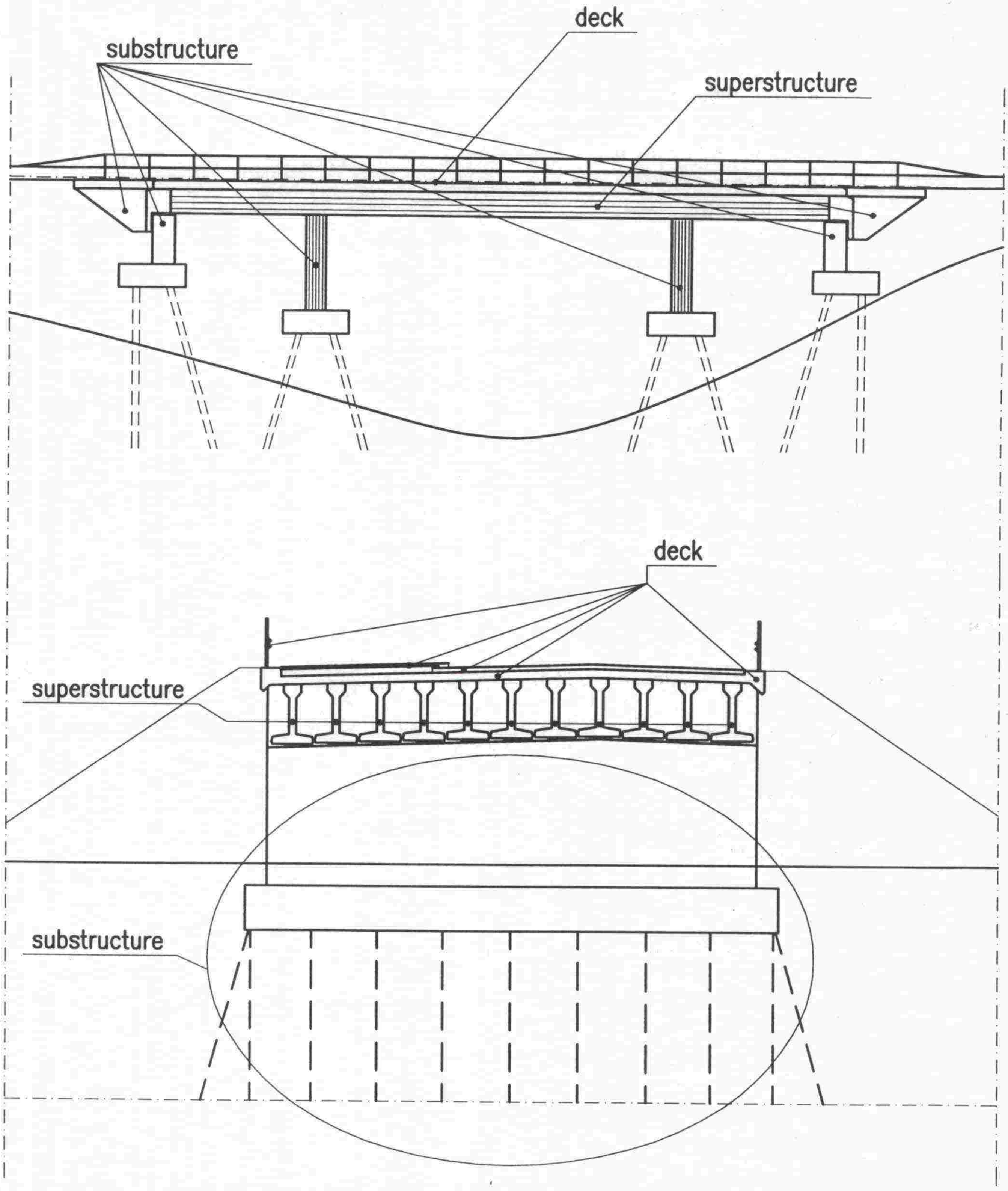


Figure 7. Structural parts of a bridge.

3.3.2.1 Condition Variables for Bridges

The overall structure of the original HIPS software includes some constraints for bridge implementation. The main results are calculated for three different bridge models. Each model includes the needed information for the analysis in five data matrices, which are created according the condition variables and condition states. The matrices are:

- Current Condition matrix
- Allowable states matrix
- Transition Probability matrix
- Agency Cost matrix
- User cost matrix

Four condition variables are used in all three models:

- superstructure condition, **S**, (3 condition classes; excellent, good, poor)
- substructure condition, **A**, (3)
- bearing capacity, **B**, (3)
- deck and edge beam condition ,**D**, (3)

Similar condition class definitions and class limits are used for all models, i.e. definitions are the same for all three ADT classes. The definition of condition variables is as follows:

Superstructure S

The condition variables and classification used are:

- Surface deterioration
- Structural cracking
- Corrosion
- Water leakage
- Honeycombing, voids

Condition class	**0**	**1**	**2**
Engineer rating class (0 - 4)	0	1 - 2	3 - 4

Substructure A

The condition variables used and their class limits are:

- Surface deterioration
- Structural cracking
- Corrosion
- Erosion damage

- Honeycombing, voids

Condition class	**0**	**1**	**2**
Engineer rating class (0 - 4)	0	1 - 2	3 - 4

Bearing Capacity

Bearing Capacity is a theoretical unit for bridges in the IMS. It is not measured periodically like road bearing capacity, though it is calculated during the design process of a bridge. The bearing capacity has a certain effect to the overall condition of the bridge. Also the foundation, poles and other construction parts are included to the bearing capacity as physical bodies. Class limits and the definition of the bearing capacity are as follows:

class	**0**	**1**	**2**
bridge age	<50y	50 - 75 y	> 75 y
weight restriction (axle, bogie, total)	none	> 8/13/25 t	8/13/25 t

Deck and Edge Beam, D

The condition variables used and their class limits are as follows (deck pavement is included to this variable, not to the road going through the bridge):

- Pavement defects
- Expansion joint
- Surface deterioration
- Cracks
- Corrosion

Condition class limits	**0**	**1**	**2**
Engineer rating class (0 - 4)	0	1 - 2	3 - 4

3.3.2.2 Current Condition

To obtain the current condition arrays, each bridge in the chosen samples is first classified according to each of the four condition variables. Then the bridge is weighted to account for bridges of different size. After that, the bridge is added to the appropriate state in the current condition array, which is finally normalised.

Bridges from the FinnRA bridge register (data as of 1 January 1993) were chosen for the estimation of bridge network current condition based on the following criteria:

- only FinnRA bridges
- no tubular bridges
- only bridges on main roads
- only concrete bridges
- only bridges with ADT data
- only bridges with length and width data
- only inspected bridges with condition estimates
- only bridges with a known construction year

Each of the three traffic volume classes, based on ADT data in the register, has its own sample. Of the total of 3032 bridges on FinnRA main roads, 139 bridges were selected for the low traffic volume network, 287 bridges for the medium network and 152 bridges for the high network. A total of 578 bridges, or 19 percent of the 3032 bridges, were selected for the samples.

The bridge register uses five condition classes numbered from 0 to 4, 0 meaning no damage, and 4 meaning serious damage. This condition classification is used both for individual damages and for various condition indices, that apply to parts of the bridge structure or to the whole bridge. In IMS only three classes are used: 0, 1 and 2, 0 meaning no damage, and 2 meaning serious damage. These three classes are used for all four condition variables.

The use of damage data for condition distribution estimation implies the aggregation of the data into the states used in IMS. This would necessarily involve the use of weighting schemes with inherent subjectivity. Therefore it was felt that the use of the condition indices supplied by the inspectors would better reflect the reality as these indices are based on case-to-case expert judgement and not on an untested automatic overall weighting scheme.

The use of condition indices is not without problems, since there are not condition indices corresponding directly to all the IMS condition variables. For the substructure there is a condition index, which is used as such for IMS. Also, there is a condition index for the superstructure excluding the edge beam but including the deck. This is used as such to describe the superstructure condition in IMS, where superstructure does *not* include the bridge deck. For the deck the condition indices for (1) the superstructure (excluding edge beam), (2) the edge beam, (3) the pavement, and (4) the surface structure (excluding the pavement) where used. After consultations with bridge experts they where weighted with 1/3, 1/3, 1/6 and 1/6, respectively, to compose the IMS deck condition index.

To estimate the bearing capacity condition of a bridge based on bridge register data poses the biggest problem when determining the current condition distribution. The bearing capacity is to a large extent a rather theoretical value based on complex calculations and this theoretical value doesn't normally deteriorate with time, except very suddenly and very abruptly. The general condition index for the whole bridge structure presumably correlates with the bearing capacity. Finally, for lack of a better solution, the project group settled for using the time since construction of the bridge to estimate the bearing capacity.

The bridge is considered to be in bearing capacity class 0 (no damage), if it was constructed less than 50 years ago. If it was constructed at least 50 but less than 75 years ago it is in class 1, and if it was constructed at least 75 years ago it is in class 2 (serious damage). This rule is used only to estimate the current condition distribution.

The bridges are weighted to account for bridges of different size. The measure chosen to describe bridge size is the area of the bridge. Because of data availability considerations the area is calculated as total bridge length times useful bridge width.

The following tables show the current condition of bridges of the high traffic volume network.

Table 3. Current condition of bridges on high traffic volume roads (in 1/10000's).

	BD								
SA	**00**	**01**	**02**	**10**	**11**	**12**	**20**	**21**	**22**
00	1 619	18	0	59	0	0	0	0	0
01	668	11	0	29	0	0	0	0	0
02	0	0	0	0	0	0	0	0	0
10	124	518	0	0	0	0	0	0	0
11	921	5 282	0	0	36	0	0	0	0
12	53	571	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	54	0	0	0	0	0	0	0
22	0	20	0	0	17	0	0	0	0

3.3.2.3 Maintenance Actions

The maintenance and rehabilitation actions are grouped from the numerous ones used in Finland into five categories according to their costs and effects. These are as follows:

Number	Description	Cost per km (in 1000 FIM)
0	Do nothing	1 - 2
1	Minor improvements	171 - 394
2	Strengthening	343 - 788
3	Superstructure rehabilitation	686 - 1575
4	Reconstruction	1028 - 2362

3.3.2.4 User Costs

The following general user cost (UC) model is used:

UC = accident cost + vehicle operating cost + travel time cost.

Accident costs include the cost from accidents on and under the bridge structure. The type and number of accidents are parts of the function.

Vehicle operation costs include increased fuel consumption and depreciation of parts resulting from vehicles having to detour due to bridge restrictions on vehicle loadings (or heights). One must estimate the number of trucks detoured per year.

For the user cost calculation for the Finnish network-level pavement management, an EXCEL-procedure has been developed. The current user cost model includes the following variables for cars and trucks:

- Average daily traffic
- Vehicle operating cost (p/unit/vehicle)
- Travel time cost (p/unit/vehicle.)
- The accident rate
- Change of accident rate due to condition variables A, D, B (%)
- The average vehicle target speed
- Change of speed due to S, A, B, D (%)
- Change of vehicle operating cost due to S, A, B, D (%)
- Additional cost of action per day per vehicle; detour due to the action (time + vehicle + speed reduction) (p/unit/vehicle)
- Length of action (days)

The Unit of User Costs

The division of bridge network in IMS is made by the average daily traffic. Due to this decision, an "average bridge" differs from one network to another. All needed input data is estimated according to this **"unit bridge, UB"**. The lengths of unit bridges are as follows:

Low traffic roads	28 m
Medium traffic roads	27 m
High traffic roads	35 m

As an example, for an unit bridge in the medium traffic network in the excellent condition state, SABD = 0000, the basic user cost can be calculated as follows:

UC(0000), Medium unit bridge/year

= average UC * lenght * average ADT * 365 d
= 2 mk/km * 0,027 km * 3000 * 365 d
= 59,13 kmk/Medium ub/year

Definition of the User Cost Model Variables

Average Daily Traffic

ADT for cars & trucks comes from RDB and they are the same as in the pavement models:

ADT class	cars	trucks	total
High	9 664	613	10 277
Medium	2 944	270	3 214
Low	1 093	114	1 207

Vehicle operating cost and travel time cost (p/unit/vehicle)

These are based on the FinnRA's annual User Cost report (1993).

The Accident Rate

These are based on the FinnRA's annual User Cost report 1993 /5/. On paved roads in Finland they are (accidents per million vehicle km):

High traffic volume	0,40
Medium traffic volume	0,42
Low traffic volume	0,46

Change of accident rate due to condition variables A, D, B (%) , (T, V, & U)

Cond. class	cars	trucks	Cond. class	cars	trucks	Cond. class	cars	trucks
A0	1	1	D0	1	1	B0	1	1
A1	1	1	D1	1	1	B1	1	1
A2	1	1	D2	1	1	B2	1	1

The Average Vehicle Target Speed

These are based on the FinnRA's User Cost report (1993) and they are:

Condition class	**cars**			**trucks**		
	ADT High	Medium	Low	ADT High	Medium	Low
S0	91	86	82	84	82	80
S1	91	86	82	84	82	80
S2	91	86	82	84	82	80

Change of speed due to S, A, B, D (%)

Cond. class	**cars**	**trucks**	**Cond. class**	**cars**	**trucks**	**Cond. class**	**cars**	**trucks**
A0	1	1	**D0**	1	1	**B0**	1	1
A1	1	1	**D1**	0.9	0.9	**B1**	1	1
A2	1	1	**D2**	0.8	0.8	**B2**	1	1

The reduction of 20 percent in speed in the table above causes extra user costs of about 3 Mmk/Mub in class B1 and 4,4, Mmk/Mub in class B2.

Change of vehicle operating cost due to S, A, B, D (%)

Cond. class	**cars**	**trucks**	**Cond. class**	**cars**	**trucks**	**Cond. class**	**cars**	**trucks**	**Cond. class**	**cars**	**trucks**
A0	1	1	**D0**	1	1	**B0**	1	1	**S0**	1	1
A1	1.15	1.15	**D1**	1.05	1.05	**B1**	5	5	**S1**	1.05	1.05
A2	1.3	1.3	**D2**	1.12	1.12	**B2**	10	10	**S2**	1.1	1.1

Additional cost of action per day per vehicle; detour due to the action (time + vehicle + speed reduction) (p/unit/vehicle/day)

Extra UC cost due to Action	**cars**			**trucks**		
	High	Medium	Low	High	Medium	Low
0 Do nothing	0	0	0	0	0	0
1 Patching	300	300	300	400	400	400
2 Strengthening	300	300	300	400	400	400
3 Rehabilitation	300	300	300	400	400	400
4 Reconstruction	300	300	300	400	400	400

Length of actions (in days)

Action length	**days**	***HIPS UC days***
0 Do nothing	0	*0*
1 Minor improvements	60	*28*
2 Strengthening	60	*28*
3 Superstructure rehabilitation	150	*70*
4 Reconstruction	200	*95*

HIPS UC days = 170 * days / 360 kmk/ub/v

Other Variables

Average detour is 30 km (defined by P.O. Linsen, Traffic Services, FinnRA)

Number of detoured trucks per day per action in the bearing capacity class 1 is 17 percent and in class 2 25 percent (estimated from the Finnish Traffic Monitoring System).

These detours have the effect through to road user cost through the Bearing Capacity condition variable. In Class 1 the extra UC costs are calculated as follows:

# of trucs * 17 % * 30 km * 365 days = ** Mmk/ ub

The following User Cost matrix shows costs for High traffic volume bridges, action do nothing. In the best condition class, SABD (0000), the cost per H bridge is 202 kmk/year.

The original HIPS condition classes 3 and 4 for S are not used in the IMS application so the numbers are defined as 9999 (like missing observations). The extra costs which maintenance actions cause to the user costs is summarized in the following effect to the user cost matrix:

Effect to costs		**min**			**max**	
	H	**M**	**L**	**H**	**M**	**L**
0 Do nothing	202	58	18	2 126	613	193
1 Minor improv.	229	66	20	2 156	621	196
2 Strengthening	229	66	20	2 154	621	196
3 S. Rehabilitation	270	77	24	2 195	632	199
4 Reconstruction	295	84	26	2 219	639	201

The negative effect of minor improvements are traffic delays, comprising about 10 percent of the normal user costs.

Effects of Condition Variables to User Costs

The effect of condition variable **Deck D** can be seen in the condition states 0000, 0001 & 0002. The costs vary from 202 to 246 e.g. **about 20 %**.

The effect of **Superstructure S** can be seen in the condition states 0000, 1000 & 2000. The costs vary from 202 to 214 e.g. **5 %**.

The effect of **Substructure A** can be seen in the condition states 0000, 0100 & 0200. The costs vary from 202 to 237 e.g. **17 %**.

The effect of **Bearing Capacity B** can be seen in the condition states 0000, 0010 & 0020. The costs vary from 202 to 1269 e.g. 600 %. That is about 1 million FIM per bridge with poor B class.

The multiplying effect of the different condition variables will increase the range of User Cost from best to worst condition class almost 2 million FIM per bridge.

Table 4. IMS User Cost for a High traffic volume unit bridge (in kmk/ year/unit bridge).

	BD								
SA	**00**	**01**	**02**	**10**	**11**	**12**	**20**	**21**	**22**
00	202	220	246	676	730	812	1 269	1 367	1 518
01	220	240	267	765	825	918	1 447	1 558	1 730
02	237	259	289	854	921	1 024	1 625	1 749	1 942
10	208	227	253	706	762	847	1 328	1 431	1 589
11	226	247	275	799	862	958	1 515	1 631	1 812
12	245	267	298	892	962	1 070	1 702	1 832	2 034
20	214	233	260	735	794	882	1 388	1 494	1 660
21	233	254	284	833	899	999	1 583	1 704	1 893
22	253	275	307	931	1 004	1 116	1 779	1 915	2 126

3.3.2.5 Transition Probabilities

The transition probabilities describe the deterioration and maintenance effect processes. Transition probabilities (TP) are estimated for each condition variable and state according to the research work done in defining Finnish Bridge Management System (SIHA) deterioration models /9/. These expert-based transition probabilities were embedded for IMS classification by the project group. The basic TP matrixes, in relation to the SIHA condition classes and the effect of other condition variables are presented in this chapter.

Do Nothing Probabilities

The expert based transition probability models for each condition variable (S, A, B, & D) are in the following form:

Year			t + 1	
	i/j	0	1	2
	0	p_{00}	p_{01}	p_{02}
t	1	0	p_{11}	p_{12}
	2	0	0	1

where:

t	ear t
t + 1	next year
0, 1, 2	conditon classification
i	condition class index for year t
j	condition class index for year t + 1
p_{00}	probability for staying in condition class 0 when the condition class in year t has been 0
p_{01}	probability to make the transition to condition class 1 when the condition class in year t has been 0
p_{02}	probability to make the transition to condition class 2 when the condition class in year t has been 0
p_{11}	probability for staying in condition class 1 when the condition class in year t has been 1
p_{12}	probability to make the transition to condition class 2 when the condition class in year t has been 1.

Two basic assumptions were made:

1 Condition can deteriorate only to the next condition class in one year, e.g. probability p_{02} is zero.
2 With no repair actions the condition class cannot improve, e.g. p_{10}, p_{20} and p_{21} are structurally set to zero.

The transition probability matrix for the whole bridge entity is combined from these four condition variable transitions. There are some constraints which ensure the homogenity of the matrixes, like non-negativity ($p_{ij} \geq 0$) and consistency constraints ($\Sigma w_{ij} = 1$).

Combined effect of other condition variables to a single condition variable were determined by the project group. The causes and their effects are as follows:

		Cause			
		S	A	B	D
	S		+	+	++
Effect	A	+		+	+
	B	+++	++		0
	D	+	0	0	

where:

0 no effect
\+ minor effect
++ strong effect
+++ remarkable effect

Thus, deck (D) and Bearing Capacity (B) are assumed to be independent (0), for example.

The numerical effects are presented in the next matrix. The column (TP) shows the probability of making a transition to condition classes (p_{01}) and (p_{12}) when the other condition variables are in excellent condition (0000).

				The effecting cond.variable (k) & the amount (%)			
			Tp (0000)	S	A	B	D
	S	p_{01} p_{12}	0.05 0.28		0.05	0.1	0.2
Effect	A	p_{01} p_{12}	0.05 0.25	0.02		0.02	0.02
	B	p_{01} p_{12}	0.01 0.01	1	0.2		0
	D	p_{01} p_{12}	0.25 0.2	0.02	0	0	

The formula for converting these transition probabilities to the basic transition probabilities is:

$$TP(S,A,B,D) = TP(p_{xx})* (1+k_S) * (1+k_A) * (1+k_B) * (1+ k_D)$$

where:

$k_{S,A,B,D}$ = The effecting condition variable value according to the condition variable and condition class from table above
$TP(p_{xx})$ = Transition probability when all other variables are in the excellent state (0000)

Superstructure S

Superstructure transition probabilities, when other condition variables are in the excellent class (class 0):

The transitions from class 1 to 2 are the SIHA transition probabilities from SIHA second worst condition class to the SIHA worst condition class e.g. they are the greatest transitions determined in SIHA Delphi-questionnaire. The transitions from class 0 to 1 were determined by the project group.

		t + 1		
		0	**1**	**2**
	0	0.98	0.02	0
t	**1**	0	0.85	0.15
	2	0	0	1

Substructure A

Substructure transition probabilities, when S, B & D are in excellent class 0.

		t + 1		
		0	**1**	**2**
	0	0.98	0.02	0
t	**1**	0	0.88	0.12
	2	0	0	1

Bearing Capacity B

Bearing capacity transition probabilities, when S, A and D are in class 0 are as follows:

		t + 1		
		0	**1**	**2**
	0	0.986	0.014	0
t	**1**	0	0.972	0.028
	2	0	0	1

The deterioration of bridge bearing capacity is assumed to be linear. In other words, it means that, for example, that after 50 years of deterioration, 50 percent of bridges have deteriorated from class 0 to class 1, comprising 1.4 percent of yearly deterioration.

Deck and Edge Beam D

Deck and edge beam deterioration probabilities are in the basic case as follows:

		t + 1: 0	1	2
t	0	0.88	0.12	0
	1	0	0.90	0.10
	2	0	0	1

Effects and Costs of Maintenance and Rehabilitation Actions

IMS has five maintenance and rehabilitation actions for bridges. These are based on the most common types of different bridge rehabilitation methods used in Finland. Nowadays, almost 95 percent of actions made by FinnRA are included to these five action categories. Each action has the transition probability matrices of its own and the definitions have been made with the FinnRA bridge experts.

The costs of different maintenance actions are average costs for a unit bridge, which was introduced in the definition of the road user costs.

0 Do Nothing

Transition probability matrices were presented above.

1 Minor Improvements

The transition probabilities are calculated according to the next table, from which the needed probabilities for each condition variable are gained by multiplying the transition of condition state needed.

	t + 1											
Cond. class	**S**			**A**			**B**			**D**		
S,A,B, D = 0	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**
t p0x	1	0	0	1	0	0	0.99	0.01	0	1	0	0
p1x	0.3	0.7	0	0.3	0.7		0	0.97	0.03	0.9	0.1	0
p2x	0.3	0.4	0.3	0.25	0.65	0.1	0	0	1	0.75	0.24	0.01

The simultaneous effect of different condition variables can be calculated from the matrix above as in the next example:

Example:

The probability of the transition from class 1002 to class 1001 after applying minor improvement -action (other variables stay in the same class but deck will be improved by one class is as follows:

$$Tp_{ij} = S_{ij} * A_{ij} * B_{ij} * D_{ij}$$

$$Tp\ (1002 \rightarrow 1001) = 0.7 * 1.0 * 0.986 * 0.24 = 0.166$$

2 Strengthening

The transitions are calculated according to the next table in the same manner as for the previous maintenance action.

Cond. class	**S**			**A**			**B**			**D**		
S,A,B,D = 0	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**
p0x	1	0	0	1	0	0	1	0	0	1	0	0
p1x	0.2	0.8	0	0.05	0.95	0	0.99	0.01	0	0.05	0.95	0
p2x	0.2	0.3	0.5	0.05	0.1	0.85	0.95	0.05	0	0.05	0.1	0.85

3 Superstructure rehabilitation

The transitions are evaluated according to the next table, where the needed transitions to each condition variable are gained by multiplying the transitions of the condition state needed.

Cond. class	**S**			**A**			**B**			**D**		
S,A,B,D = 0	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**	**px0**	**px1**	**px2**
p0x	1	0	0	0.98	0.02	0	1	0	0	1	0	0
p1x	0.99	0.1	0	0	0.88	0.12	0.75	0.25	0	0.95	0.05	0
p2x	0.99	0.01	0	0	0	1	0.4	0.5	0.1	0.95	0.05	0

4 Reconstruction

The transitions are evaluated according to the next table, where the needed transitions for each condition variable are gained by multiplying the transitions of the condition state needed.

Cond. class	S			A			B			D		
S,A,B,D = 0	px0	px1	px2	px0	px1	px2	px0	px1	px2	px0	px1	px2
p0x	1	0	0	1	0	0	1	0	0	1	0	0
p1x	0.99	0.01	0	0.97	0.03	0	1	0	0	0.95	0.05	0
p2x	0.99	0.01	0	0.99	0.01	0	0.99	0.01	0	0.95	0.05	0

3.3.2.6 Allowable States and Actions

Do-nothing action is allowed to all condition states. Other actions are allowed mainly to all states, except the best ones, like 0000 in the case of reconstruction.

4 TRAINING PACKAGE

4.1 Description

This part of training is anticipated to take one full day, divided into two phases:

1 Theory 4 hours
2 Working examples 4 hours

The first part consists of the theory of (a) economical decision-making, concentrating on the use of the standard economical indicators in decision-making; and (b) Infrastructure Management System, concentrating on the steps to be taken when using a management information system as a decision support tool. The training material to be used in this analysis consists of the topics included in Chapter 3.2.

The second part consists of a working example with a real data set and real practical problem. In this first example, a data set of the main road network of Finland is analyzed, starting from the data preparation and ending into the optimal rehabilitation budget and resource allocation for pavements and bridges. The training material to be used in this analysis consists of the topics included in the Chapter 3.3 and in the following Chapter 4.2.

A tentative outline for the second part of this training is in Appendix 4.

4.2 Case Example

4.2.1 Introduction

Finnish National Roads Administration is responsible for its main road network, comprising 12 000 km of roads and 4000 bridges. For this IMS analysis, this infrastructure is divided into three sub-networks according to the average daily traffic (ADT). We thus get six models, three for roads and three for bridges. The size of this infrastructure is shown in the following table.

	> 6000	**1500 - 6000**	**< 1500**
roads	2 179	5 852	3 887
unit bridges	932	938	392

The main problem of FinnRA in maintaining these structures is to allocate money for these models under certain multi-criteria goals, such as minimal allowable condition and budgetary constraints. The investment period is rather arbitrarily taken as eight years.

The allocation raises several questions to decision-makers:

- What is the current condition of the network?
- What would be the optimal condition?
- What is the optimal budget for each model?
- What is the optimal allocation between the models under a given budget?
- What are the optimal maintenance policies under given budgets and what are their consequences?
- How profitable are different maintenance policies?

This decision situation is complicated due to the fact that there is no clear single goal but several goals which are partly contradictionary. One might, say, try to minimize maintenance costs, another maximize road condition at the end of the period, third decision-maker might aim at quick repayment of the money invested in terms of lowered user costs.

The budget for the total network is expected to be about 210.000 units of money (1 unit = 1000 FIM = 160 USD). The minimum constraint for each model equals 6 units of money per one kilometer or one unit bridge. This constraint ensures the lowest feasible traffic conditions. Note that this differs from the Do-nothing policy, where only routine maintenance is carried out.

The current condition of the network to be analyzed is as follows (in marginal distributions):

		pavement high	pavement medium	pavement low
Roughness	T0	45.0	41.8	31.7
	T1	52.0	54.1	60.2
	T2	3.0	4.1	8.1
Bearing capacity	K0	71.8	80.6	68.2
	K1	6.8	5.5	13.2
	K2	7.3	5.6	6.7
	K3	4.5	2.9	4.9
	K4	9.6	5.4	7.0
Defects	V0	95.9	86.1	77.5
	V1	3.5	11.3	17.1
	V2	0.6	2.6	5.4
Rutting	U0	94.1	97.9	98.5
	U1	3.4	1.7	1.0
	U2	2.5	0.4	0.5

		bridges high	bridges medium	bridges low
Sub-structure	A0	23.4	21.9	38.2
	A1	70.0	75.4	57.6
	A2	6.6	10.7	4.2
Super-structure	S0	24.0	20.9	30.6
	S1	75.1	75.8	64.8
	S2	0.9	3.3	4.6
Deck	D0	34.7	29.7	41.2
	D1	65.3	69.5	54.7
	D2	0.0	0.8	4.0
Bearing capacity	B1	98.6	99.1	99.5
	B2	1.4	0.9	0.5
	B3	0.0	0.0	0.0

4.2.2 IMS Technical Overlook

When started for training purposes, IMS already contains the following input data for each model:

- current condition
- agency costs for each action
- user costs for each action
- deterioration models for all condition variables
- maintenance action alternatives (do-nothing vs. other actions)
- maintenance effect models for all condition variables

For the economic analysis, the following IMS runs are to be executed:

- long-term model (optimal condition level)
- short-term models with do-nothing policy
- short-term models for policies with different budget constraints

The outputs from these runs consists of

- condition distribution in eight successive years
- social costs, agency costs and user costs in eight successive years
- maintenance policies

The cost data will be used as input for economic analysis programs.

4.2.3 Case Example: Economic Part

As an example, the model Pavement Medium is used.

Table 5 contains an IMS short-report of unconstrained run for model Pavement Medium. The leftmost column (1993) contains the current condition distributions and rightmost column the long-term equilibrium target condition distribution, defined by the unconstrained long-term IMS-run. Roughness and bearing capacity are currently below the optimal condition whereas defects and rutting are slightly above. In the final analysis year (2001), other condition variables except bearing capacity have reached their target in eight years.

Costs on the user cost row are nearly equal showing that the policy has, even in a long run, only a slight effect on user costs. This shows that the overall condition of roads in this model remains the same over the analysis period. The improvement of roads with respect to roughness and bearing capacity is thus compensated by the slight deterioration of defects and rutting.

Table 5. Short-term run of Pavement Medium.

ANNUAL RESULTS	1993	1994	1995	1996	1997	1998	1999	2000	2001	Target
Percent by State Class										
Roughness T0= IRI 0.-1.49	42.010	51.630	51.630	51.431	51.505	51.537	51.549	51.561	51.571	51.630
T1= IRI 1.5-3.5	53.970	46.190	47.054	47.340	47.340	47.340	47.340	47.340	47.340	47.340
T2= IRI >3.5	4.020	2.180	1.316	1.229	1.155	1.123	1.111	1.099	1.089	1.030
Bearing K0= >260 MN/m2	80.180	90.523	92.678	94.169	95.316	96.200	96.890	97.432	97.858	98.910
Capacity K1= 241-260 MN/m2	5.700	5.188	5.076	4.355	3.701	3.136	2.655	2.253	1.920	1.060
K2= 221-240 MN/m2	5.660	2.221	1.087	0.822	0.611	0.451	0.331	0.244	0.180	0.030
K3= 201-220 MN/m2	2.940	0.605	0.371	0.230	0.143	0.089	0.056	0.035	0.022	0.000
K4= <=200 MN/m2	5.520	1.464	0.789	0.425	0.229	0.124	0.067	0.036	0.020	0.000
Defects V0= < 1% length	85.170	79.320	79.320	79.320	79.320	79.320	79.320	79.320	79.320	79.320
V1= 1-20% length	12.170	18.390	18.029	18.118	18.148	18.216	18.271	18.308	18.335	18.390
V2= >20% length	2.660	2.290	2.651	2.562	2.532	2.464	2.409	2.372	2.345	2.290
Rutting U0= 0-13 mm	97.860	94.544	95.323	95.330	95.330	95.330	95.330	95.330	95.330	95.330
U1= 14-19 mm	1.650	5.352	4.630	4.630	4.630	4.630	4.630	4.630	4.630	4.630
U2 >19 mm	0.490	0.104	0.047	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Acceptable Percent	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	
Weighted deviation	1598	439	290	218	165	124	92	67	48	
% deviation reduced	0	73	82	86	90	92	94	96	97	
Total km / year	3659	3659	3659	3659	3659	3659	3659	3659	3659	
Budget Maximum kFIM/km	---	---	---	---	---	---	---	---	8-YEAR	
Minimum kFIM/km	---	---	---	---	---	---	---	---	TOTAL	
Social Cost kFIM/km	2148.00	2060.08	2052.38	2049.54	2047.56	2046.53	2045.91	2045.51	16495.50	
User Cost kFIM/km	2033.29	2023.68	2021.53	2021.09	2020.77	2020.59	2020.49	2020.42	16181.86	
Agency Cost kFIM/km	114.71	36.40	30.85	28.45	26.78	25.94	25.42	25.09	313.64	
Total Agency Cost kFIM/yr	419733	133199	112866	104098	98000	94903	93012	91796	1147607	
0-Do nothing	2190	3076	3088	3122	3131	3131	3132	3135	24004	
1-Rut patching	566	0	25	23	21	17	28	28	709	
2-General patching	30431	0	984	460	368	533	576	573	33927	
3-Planing/AC added	2860	19506	14632	9259	8762	8398	8015	7751	79183	
4-New thin overlay	44528	56605	67209	75467	76361	77185	77801	78146	553302	
5-New thick overlay	37539	10974	3002	2328	1765	1323	988	737	58655	
6-Light reconstruction	0	0	0	0	0	0	0	0	0	
7-Heavy reconstruction	301619	43038	23927	13439	7591	4316	2471	1426	397827	

IMS recommends mostly new thin overlay on the whole analysis period, general patching in two first years and heavy reconstruction after the first year.

For the economic analysis of model Pavement Medium, the results from several IMS runs are collected in the database beforehand. First we compare policies with five different budget constraint ranging from 11 to 15. The first sheet (Figure 8, Appendix 5) shows the basic results from the **ECON** program. First figure shows that there is only a slight difference in the costs of these policies. This is due to the fact that in each policy only minor reparations are made. The IRR of the policies are also near each other ranging from 24 % to 31 %. In almost every case they will be profitable. Policies pm12 and pm11 have the highest IRR of 31 %, showing that they are least sensitive to the discount rate. However, it does not show that they would be the most profitable with some smaller discount rate as 10 %. The second figure shows the gain from each policy with when compared to the do-nothing policy pm0. Again the results for all policies are similar. With a discount rate 10 % the net present value is largest (24) for policies pm12 and pm13 indicated that in such case these are the most profitable ones. The last figure shows that each policy pays the investment back in about six years.

The second sheet (Figure 9) shows the basic results from the **GAIN** program for each of the policies. The results show that the NPV of 24 is achieved for policy pm13 with an agency cost of 55 and for policy pm12 with agency cost 49. When these two policies are further considered, the marginal revenue of policy pm13 equals 0.96 showing that the gain from the last dollar invested after policy pm12 is only 96 cents and the extra investment is, therefore, unprofitable. Thus, we choose policy pm12 as the optimal one.

The next sheet (Figure 10) gives more information for the optimal policy pm12 with respect to the four other ones. The IRR of pm13 with respect to pm12 is 8 % showing that policy pm13 might also be more profitable than pm12 if the discount rate is smaller than 8 %. The third figure shows that for most policies, the chosen policy pm12 has a larger cumulative gain in all of the eight years.

If one wants to reach the target as quickly as possible, i.e. with no budget constraint, the IMS results show that one should choose policy popt. It, however, is unprofitable, as one can see from Figure 11. The policy leads to heavy investments in three first years as can be seen from the first figure in Figure 11. The investment gives later a higher payoff in terms of decreased user costs. But, the NPV of the policy is negative and the policy is unprofitable. The IRR is 0 % (or even negative) indicating that the policy will in fact never be profitable. The reason for this can be seen in the third figure. The policy will get break-even in ten years or so but the user cost gain comes so slowly that with our eight year analysis period the policy will fail.

As another example we consider the model Bridges Medium. Now, the three policies considered with budgets 5 to 9 have IRR ranging from 18 to 31 (Figure 12). The NPV criterion shows that policies bm14 and bm13 will be the most profitable ones. The third figure shows that all these policies pay the investment back in about eight years.

In our case example of model Pavement Medium, policy pm12 was the most profitable one; policies with larger agency costs have smaller payoff in terms of social costs and they are in both respects less profitable. When the same analysis is performed for all models, the optimal policies become as follows (Figure 13):

model	kFIM/km	total (1000 FIM)
pavement high	39	84.981
pavement medium	12	70.224
pavement low	6	23.322
	kFIM/ub	
bridges high	36	33.552
bridges medium	14	13.132
bridges low	5	1.960
TOTAL		**227.171**

The total of these is about 227 Million FIM, which is larger than the expected budget. Hence, it is not possible to keep all models in the economical optimum and some of them have to be decreased. This kind of tuning is carried out using program MODEL. As a rule, the budget of the model with smallest marginal cost reduction is reduced. It often happens that several models have marginal cost reduction of the same size. In such a case, the decision-maker may use his expertise and reduce the budget of some other model, too. This way it is possible to take into account details which are important though not included in the models. So it is possible that different persons end up to different resource allocation solutions.

model	kFIM/km	total (1000 FIM)
pavement high	38	82.802
pavement medium	10	58.520
pavement low	6	23.322
	kFIM/ub	
bridges high	35	32.620
bridges medium	11	10.318
bridges low	5	1.960
TOTAL		**209.542**

The results in Figure 13 show that the marginal gain has dropped slightly but the average cost has increased.

5 CONCLUSIONS

This very ambitious project was carried out with success. The original objective was to develop a software training package to the use in the World Bank's training program for highway management i.e. optimizing the economical management of a nation's pavements and bridges. However, the result was a useful software package to be used in road administration's daily strategy planning purposes instead of not only for training purposes. The results so far seem very promising to be used in the Finnish Road Administration's strategy setting.

Of course the bridge models and data require more research, especially the user costs. However, with the existing software version and data the mathematical, economical optimum can be found with the pavements and bridges simultaneously. This kind of operational tool for managers hasn't been introduced yet among the road engineering professionals.

The developed tool is meant to be for the use of, especially, the top managers of the road administration, but also for the lower level managers and paving and bridge engineers. It brings the optimization and economical points of view very clearly into decision-making at the network level. The framework of the software can basically be used with optimizing of any infrastructures of the society with the following notion; data collection and modelling work has to be done beforehand.

The advantages of the presented approach are:

- it fits for the top manager's decision making tool
- it is the first approach introducing theoretically "right" optimization between apples and oranges e.g. pavements and bridges
- it is good for training purposes but fits also for every day's decision-making in road administration
- the training package is flexibly changeable for different levels of management

The project is now finished though the testing of software with the real data continues until the end of October 1993.

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Memorandum of Understanding

Introduction and Background

1. Dr. Pedro Geraldes, from the Economic Development Institute (EDI) of the World Bank, visited Helsinki from December 14 to 18, 1992 to, inter-alia, prepare with Finnish officials a proposed framework for cooperation between the Government of Finland (GOF) and EDI's Infrastructure and Urban Development Division (EDINU). Dr. Geraldes' mission follows on contacts established during 1992, both in Finland and the U.S.A., between EDINU Higher-Level Management and Senior Officials from the GOF. The activities of the Mission were conducted in close cooperation with staff from the Ministry of Foreign Affairs (MOFA) and from the Ministry of Transport and Communications (MOTC), as well as from the Finnish National Road Administration (FINNRA) and its Institute for Highway and Maritime Education (IHME). The present Memorandum of Understanding summarizes the consensus reached during the Mission's visit which are subjected to further confirmation by the World Bank.

Objectives

2. The framework for cooperation would focus on a transport training program for senior sector managers and trainers from Republics of the Former Soviet Union (FSU), especially the Russian Federation and the Baltic countries, and from selected Central and Eastern European countries. It would cover a period of three years, during which a total of nine activities (each lasting for up to two weeks) would be delivered in Finland for the benefit of about 180 senior managers and some 45 professors from Universities and sector Research Institutes. The recommended targeting is aimed at the progressive internalization of the training effort within the beneficiary countries, with the ultimate goal of enabling local training institutions to directly deliver the training activities.

Scope

3. Consistently with identified needs, and agreed priorities, the training program would aim at the development of strategic and analytical skills of the targeted trainees in support of the implementation of sector reforms. In this context, the program would address transport policy and operational issues, with emphasis on pricing and resource mobilization, economic and financial analysis of capital investment projects, environmental assessment, liberalization and private sector development, and business administration. The above issues would be aggregated under three product lines of training activities, as indicated in the following. It is anticipated that some of the training modules could be jointly used in the delivery of two or more of the identified product lines.

4. Transport Management Development Program (TMDP). This product line would comprise three training activities, i.e., one to be delivered each year. Participant managers would be identified among public sector officials already involved, or likely to be involved, in the preparation and appraisal of transport investments financed by multilateral financial institutions, including the World Bank. Program contents would cover fundamentals of transport economics; the project cycle with emphasis on the economic, financial and environmental analysis of projects; infrastructure management systems; logistics management; and procurement. In addition, a module would be specifically focussed on the origin and role of, as well as on the procedures followed by, international financial institutions including the mobilization of co-financing from bilateral and multilateral sources.

5. Executive Program on the Management of Transport Operations. Three activities are also considered under this product line, i.e., one in each year. This Executive Program would address training requirements of public sector officials and of industry managers with a view to enable them to operate in an environment characterized by increasing enterprise autonomy and competitiveness. One of the topics to be covered would be sector organization in market economies, with emphasis on the role of the Government in setting up the regulatory framework for private sector operators. Other topics to be covered would include logistics, marketing and personal management, as well as cost-accounting and financial management of transport enterprises. The importance of Management Information Systems (MIS) would be addressed, as a basis for improved enterprise performance. The role of the financial system in support of industry development and rationalization would also be covered.

6. Construction and Consulting Industry Program. This product line would comprise the delivery of three training activities, i.e., also one per year. This Program would address training requirements of industry managers and regulators, toward the development of a market-based construction and consulting industry in the transport sector. Key policy-topics to be covered would include the policies, procedures and programs to address the major constraints to the development of a private-sector led industry; the building-up of the institutions required to ensure professional and quality standards; and the development of a business environment which encourages quality and competitiveness. Other topics to be covered would include business administration techniques for sector enterprises and the role of joint ventures with foreign firms as providers of seed capital and technology. The opportunities offered by Multilateral Development Finance Institutions to the development of a private-led and internationally competitive domestic industry would also be addressed.

Delivery

7. In line with the above assistance strategy, the training activities would combine lecture modules on the selected topics with small group workshops on subjects considered to be of more immediate relevance to the beneficiaries.

These subjects would be identified by the Program managers, in close cooperation with the targeted participants. The proposed delivery methodology would also emphasize field visits to selected transport facilities in Finland, so that participants would gain hands-on experience on how to practically address their problems.

Financing

8. Based on available information, it is estimated that a total of about US$900,000 equivalent, i.e. some US$300,000 per year, would be required to finance program preparation and delivery, including participants' identification and activity follow-up in the beneficiary countries. The cooperation program would be co-financed by the GOF, with EDINU's contribution amounting to some US$100,000 per year. In order to increase administrative effectiveness, parallel co-financing would be used. In this context, EDINU's contribution would be targeted at the financing of: (i) participation of non-Finnish lecturers/resource persons in the preparation and delivery of training activities; (ii) translation of training materials; (iii) provision of interpreters; (iv) travelling of participants to Finland; and (v) Bank's Task Management expenses. The contribution of the GOF is expected to be targeted at the financing of local costs in Finland, including services provided by domestic consulting firms and local logistics expenses.

Management

9. The program would be jointly managed by a Task Force comprising a Program Director to be appointed by the MOTC, by the Director of the IHME and by the responsible EDINU's Task Manager. The Task Force would ensure the day-to-day running of the Program, including joint missions to the targeted countries to identify needs and participants, and to follow up on the outcome of training activities. At least once a year, a meeting would take place between Higher-level Management from EDI and Senior Officials from MOFA and MOTC with a view to monitor program implementation, confirm the yearly funding levels, and approve the following year's activity program, including sub-regional targeting.

Case-Study

10. The Terms of Reference for the Case-Study on Infrastructure Management Systems are attached as Annex 1. The Case-Study would be immediately used as training material for the TMDP. It is expected to be completed by end-July, 1993, for a total cost of about US$200,000 equivalent to be funded by the GOF. EDINU would bear the additional costs to be incurred with the editing, translation, publication and diffusion of the Case-Study. At a latter stage, it is expected that the Case-Study would be integrated in the normal program of EDINU's activities worldwide.

Further Actions

11. A follow-up EDINU Mission would visit Helsinki for a period of one week on/or about March 8, 1993. The main objectives of the Mission would be to firm up with MOTC, the IHME, and the Program Director the: (i) specific contents of each Program activity; (ii) calendar for activity delivery, now tentatively scheduled to be initiated by October, 1993; (iii) local logistics arrangements; (iv) Activity Briefs, including the detailed budgets, for the activities included in the first year of the Program; and (v) progress in the preparation of the Case-Study on Infrastructure Management Systems. Benefiting from the Mission's presence in Finland, a first joint visit to the Baltic countries could take place during that period.

Attachment

Helsinki, December 18, 1992

Juhani Korpela
Secretary General
Ministry of Transport and Communications

Pedro Geraldes
Economic Development Institute
The World Bank

THE WORLD BANK/IFC/MIGA

OFFICE MEMORANDUM

APPENDIX 2

DATE: December 16, 1992

TO: Mr. Raimo Tapio, Finnish National Road Administration (FINNRA)

FROM: Pedro Geraldes, EDINU

EXTENSION: 3-6269

SUBJECT: Infrastructure Management System
Preparation of Case-Study

Background

1. The Economic Development Institute of the World Bank, through its Infrastructure and Urban Development Division (EDINU), is entering into a cooperative framework with the Government of Finland with a view to prepare and deliver a pluriannual training program. Program beneficiaries would be sector managers and trainers from Republics of the Former Soviet Union, especially the Russian Federation and the Baltic countries, and from selected Central and Eastern European countries. A key component of the training program is a Transport Management Development Program (TMDP) aimed at enhancing the strategic and analytical skills of participating trainees. It is anticipated that the majority of TMDP participants would be Government officials more directly involved in the identification and preparation of investment projects to be appraised by the Bank and other multilateral finance institutions.

2. The strategy to be followed in the preparation of training materials for the TMDP emphasizes the use of computer-aided decision-making techniques, based on economic benefit-cost concepts. Of paramount importance among these techniques are management systems allowing for a rational allocation of resources to the development and operation of infrastructure networks, including (but not limited to) roads. Such systems basically allow for an economic-based optimization of network expenditures, subject to budgetary constraints, based on the analysis of the trade-offs between user and infrastructure costs. As such, they have to comprehensively consider all the main expenditure items associated with the network under consideration, such as bridges and pavements in the case of road networks. Furthermore, they have to incorporate discounted cash flow techniques, so that investment efficiency indicators can be estimated for each investment alternative associated with a pre-specified level of budgetary availability.

Objectives

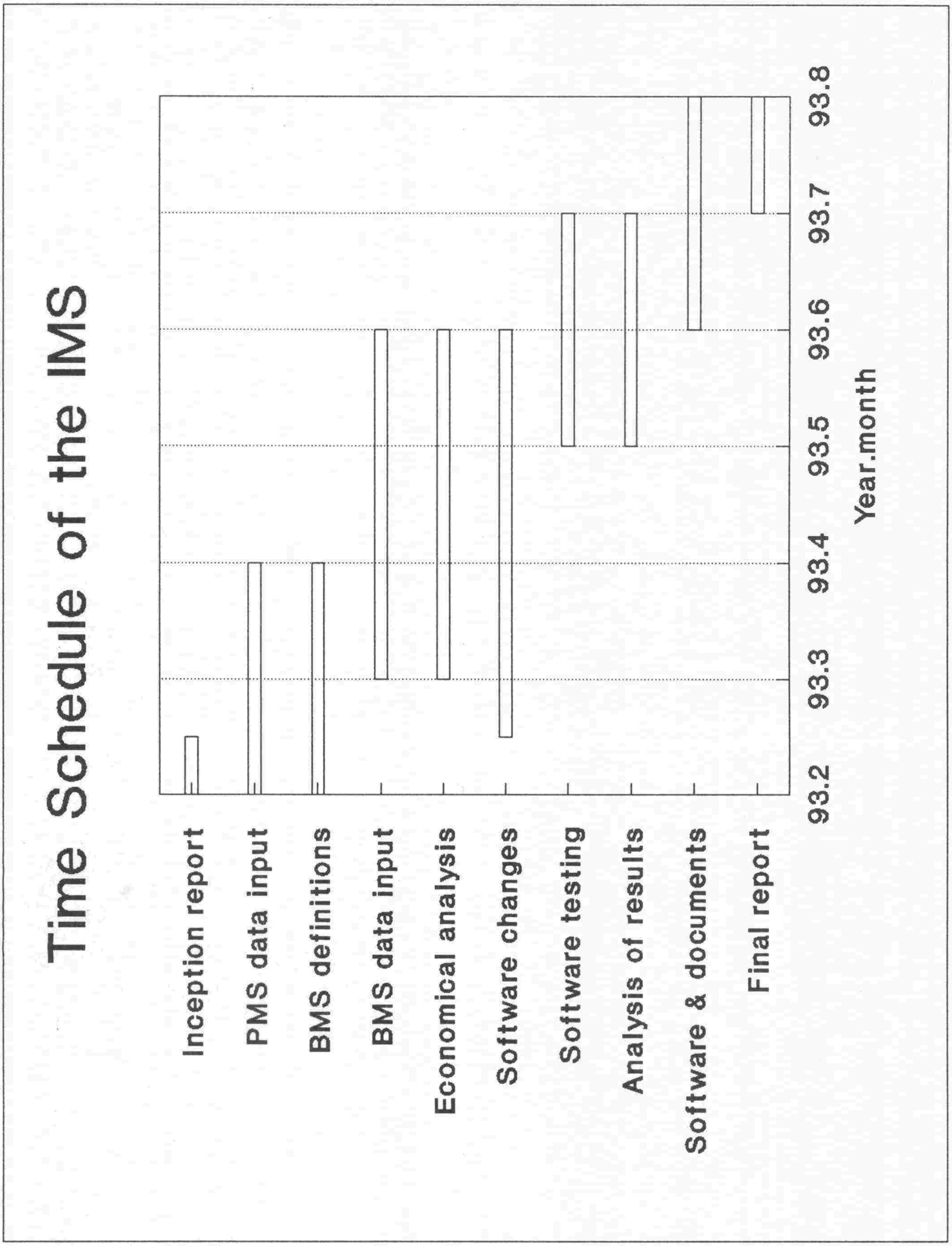
3. The chief aim of the assignment would be to upgrade the Pavement Management System (PMS) and the Bridge Management System (BMS), currently being used by FINNRA, in order to prepare a case-study on Infrastructure Management System (IMS) capable of meeting TMDP's training requirements. A summary structure of the IMS is presented in the Attachment. As such, the main objectives of the assignment are to:

(i) incorporate the quantification of Vehicle Operating Costs (VOC) into the BMS, toward the analysis of trade-offs between user and infrastructure costs;

(ii) allow for the consideration of diverted traffic effects within the BMS, through the incorporation of a minimum-cost VOC algorithm;

(iii) consolidate the BMS with the PMS, so that they can be jointly optimized under one budgetary constraint; and

(iv) prepare training documentation.


Time Schedule of the IMS
Inception report
PMS data input
BMS definitions
BMS data input
Economical analysis
Software changes
Software testing
Analysis of results
Software & documents
Final report
93.2
93.3
93.4
93.5
93.6
93.7
93.8
Year.month

A TENTATIVE OUTLINE FOR TRAINING

This tentative program is for the practical part of IMS. It is assumed that the theory of economical decision-making is already known.

LESSON 1 (60 min)

- What is the purpose of this training package?
- What is IMS?
- Structure of IMS
- Six models of IMS
- Input data
  - current condition
  - user costs and agency costs
  - maintenance actions
  - deterioration models
- Short term/Long term models
- Different policies
  - Do-nothing policy
  - Budget constraints policies
- How to read the results

Break (20 min)

LESSON 2 (45 min)

- Economic indicators
- Program ECON
  - Data acquisition
  - Do-nothing policy
  - Interpreting the figures and ratios
- Program GAIN
  - Data acquisition
  - Social cost reduction as a function of agency costs
  - Marginal costs
  - Interpreting the results
- Program MODEL
  - Data acquisition
  - Resource allocation process
  - Interpreting the results

Break (10 min)

LESSON 3 (60 min)

- Case example
  Introduction
  Program ECON
  Program GAIN
  Program MODEL
  Conclusions
- Conclusions of this part of training

Break (15 min)

LESSON 4 (voluntary)

- Practical use of IMS

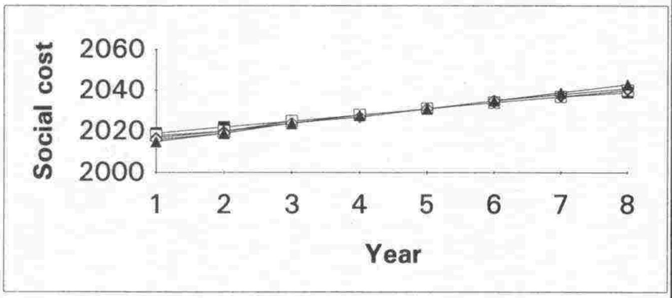
IMS Economic Analysis 20.7.1993

Pavement medium			social cost		
pm0	pm15	pm14	pm13	pm12	pm11
2005	2019	2018	2017	2016	2015
2013	2022	2020	2020	2019	2019
2021	2025	2025	2024	2024	2024
2030	2028	2028	2027	2027	2028
2040	2031	2031	2031	2031	2031
2050	2034	2034	2034	2035	2035
2060	2037	2037	2037	2038	2039
2070	2039	2040	2040	2041	2043

Data acquisition

1. Select database file from Window menu.
2. In the data base select policy/policies .
3. Click right button. Select copy.
4. Select ECON.WLS from the Window menu.
5. Select cell A2-F2. (A2 for the reference policy)
6. Click right button. Select paste.
7. Name data set in green cell A1.

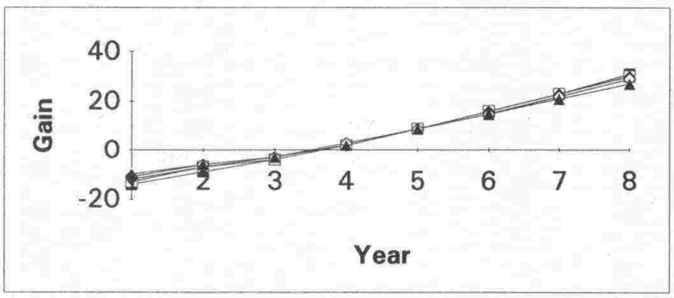
Order of colors is red, green, blue, yellow, pink.



The first figure gives social costs from each policy excepting the reference policy.

IRR	24%	26%	29%	31%	31%

IRR gives the largest discount rate for which the investment is profitable.



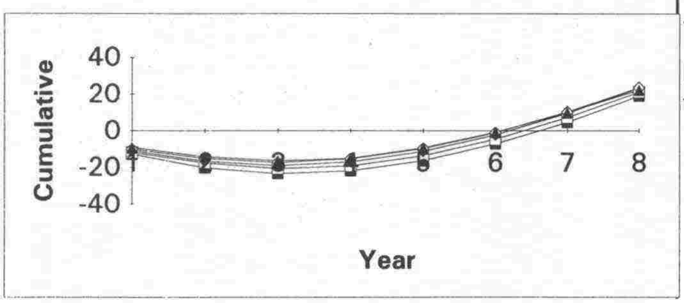
The second figure shows the gain when substracted from the reference policy.

Calculation of the Net Present Value

Write the discount rate in the red cell A32. It can be changed when necessary.

NPV	19	21	24	24	22

NPV gives the net value of each policy with given discount rate.



The third figure gives the year, when each policy becomes profitable when compared to the reference policy.

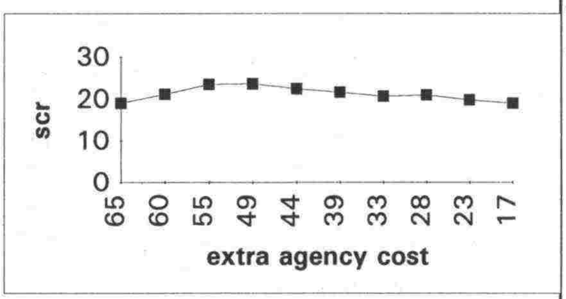
Figure 8.

IMS Economic Analysis 20.7.1993

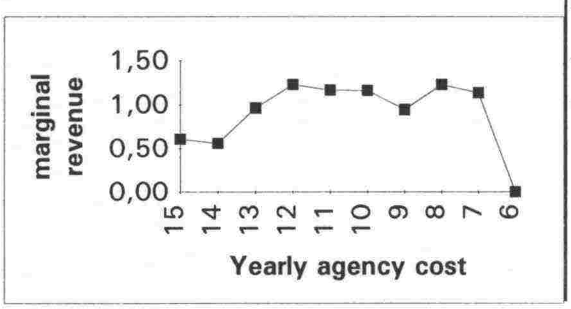
Pavement medium			social cost		
pm0	pm15	pm14	pm13	pm12	pm11
2005	2019	2018	2017	2016	2015
2013	2022	2020	2020	2019	2019
2021	2025	2025	2024	2024	2024
2030	2028	2028	2027	2027	2028
2040	2031	2031	2031	2031	2031
2050	2034	2034	2034	2035	2035
2060	2037	2037	2037	2038	2039
2070	2039	2040	2040	2041	2043

Pavement medium			agency cost		
pm0	pm15	pm14	pm13	pm12	pm11
1	15	14	13	12	11
2	15	14	13	12	11
2	15	14	13	12	11
3	15	14	13	12	11
3	15	14	13	12	11
4	15	14	13	12	11
4	15	14	13	12	11
5	15	14	13	12	11

agency	65	60	55	49	44
scr	19	21	24	24	22



agency	15	14	13	12	11
marginal	0,61	0,56	0,96	1,23	1,17



Data acquisition

1. Select database file from Window menu.
2. In the data base select policy/policies .
3. Click right button. Select copy.
4. Select GAIN.WLS from the Window menu.
5. Select cell A2-F2. (A2 for the reference policy)
6. Click right button. Select paste.
7. Name data set in cell A1.

Order of colors is red, green, blue, yellow, pink.

Ten different policies may be compared though only five are shown on the monitor.

Social and agency costs can be read also simultaneously.

Setting the discount rate

Write the discount rate in the red cell A22. It can be changed when necessary.

Table gives user cost reduction , agency cost

The first figure gives social cost reduction as a function of agency cost in eight years.

Table gives first year agency cost for each policy and marginal social cost reduction (gain from last dollar invested) for each policy.

The second figure gives marginal gain as a function of first years agency cost.

Figure 9.

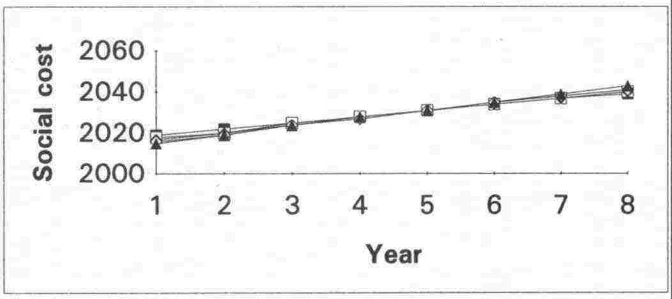
IMS Economic Analysis 20.7.1993

Pavement medium			social cost		
pm12	pm15	pm14	pm13	pm12	pm11
2016	2019	2018	2017	2016	2015
2019	2022	2020	2020	2019	2019
2024	2025	2025	2024	2024	2024
2027	2028	2028	2027	2027	2028
2031	2031	2031	2031	2031	2031
2035	2034	2034	2034	2035	2035
2038	2037	2037	2037	2038	2039
2041	2039	2040	2040	2041	2043

Data acquisition

1. Select database file from Window menu.
2. In the data base select policy/policies .
3. Click right button. Select copy.
4. Select ECON.WLS from the Window menu.
5. Select cell A2-F2. (A2 for the reference policy)
6. Click right button. Select paste.
7. Name data set in green cell A1.

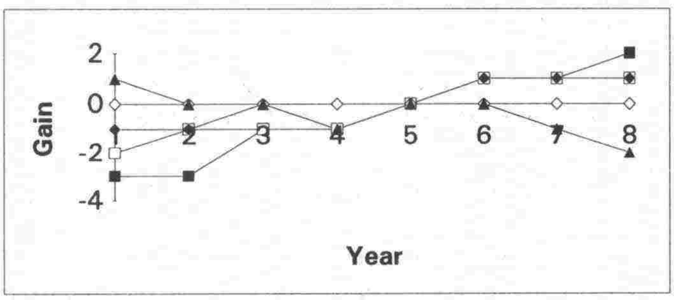
Order of colors is red, green, blue, yellow, pink.



The first figure gives social costs from each policy excepting the reference policy.

IRR	0%	0%	8%	0%	0%

IRR gives the largest discount rate for which the investment is profitable.



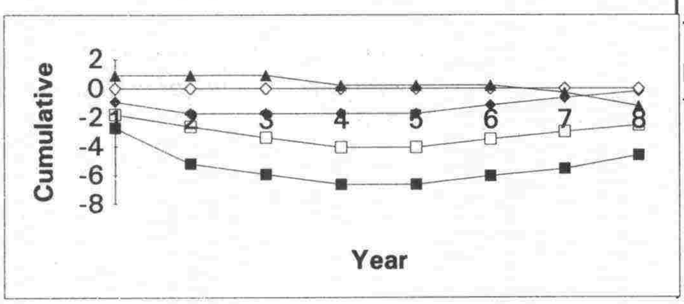
The second figure shows the gain when substracted from the reference policy.

Calculation of the Net Present Value

Write the discount rate in the red cell A32. It can be changed when necessary.

NPV	-5	-3	0	0	-1

NPV gives the net value of each policy with given discount rate.

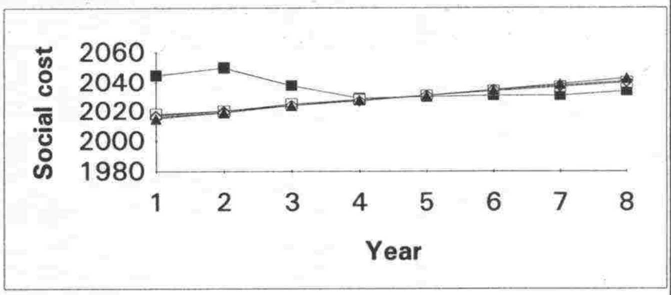


The third figure gives the year, when each policy becomes profitable when compared to the reference policy.

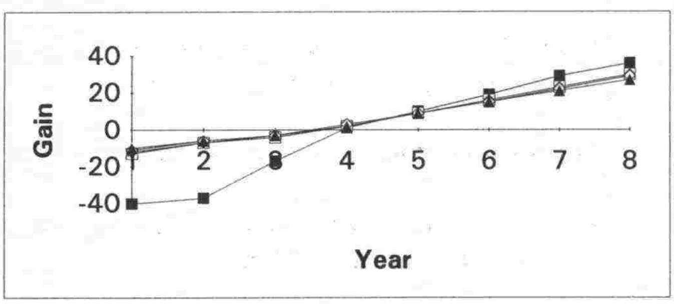
Figure 10.

IMS Economic Analysis 20.7.1993

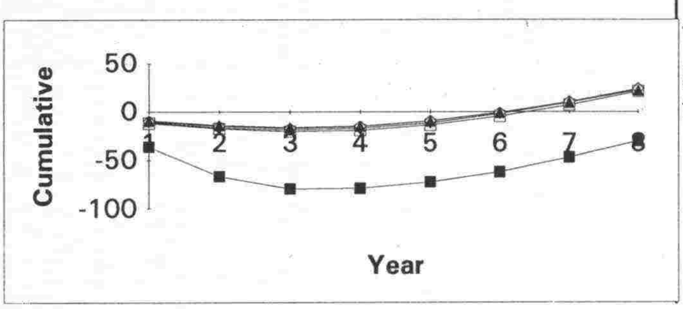
Pavement medium			social cost		
pm0	popt	pm14	pm13	pm12	pm11
2005	2045	2018	2017	2016	2015
2013	2050	2020	2020	2019	2019
2021	2038	2025	2024	2024	2024
2030	2029	2028	2027	2027	2028
2040	2030	2031	2031	2031	2031
2050	2031	2034	2034	2035	2035
2060	2031	2037	2037	2038	2039
2070	2034	2040	2040	2041	2043



IRR	0%	26%	29%	31%	31%



NPV	-30	21	24	24	22



Data acquisition

1. Select database file from Window menu.
2. In the data base select policy/policies .
3. Click right button. Select copy.
4. Select ECON.WLS from the Window menu.
5. Select cell A2-F2. (A2 for the reference policy)
6. Click right button. Select paste.
7. Name data set in green cell A1.

Order of colors is red, green, blue, yellow, pink.

The first figure gives social costs from each policy excepting the reference policy.

IRR gives the largest discount rate for which the investment is profitable.

The second figure shows the gain when substracted from the reference policy.

Calculation of the Net Present Value

Write the discount rate in the red cell A32. It can be changed when necessary.

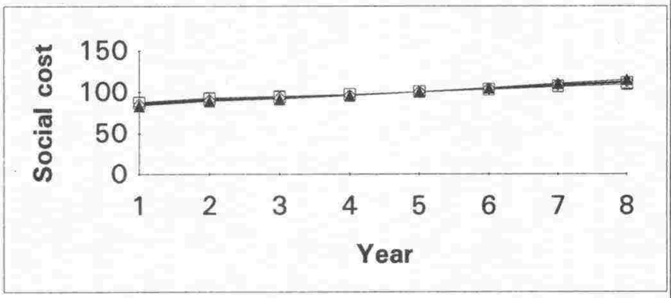
NPV gives the net value of each policy with given discount rate.

The third figure gives the year, when each policy becomes profitable when compared to the reference policy.

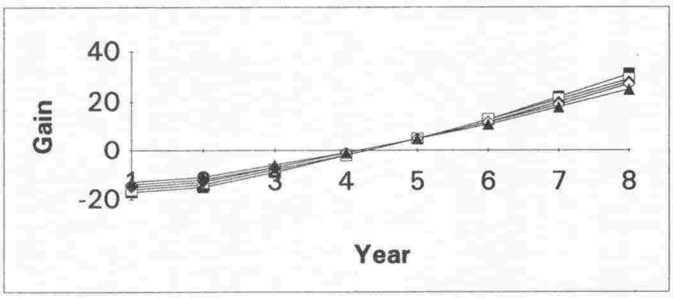
Figure 11.

IMS Economic Analysis 20.7.1993

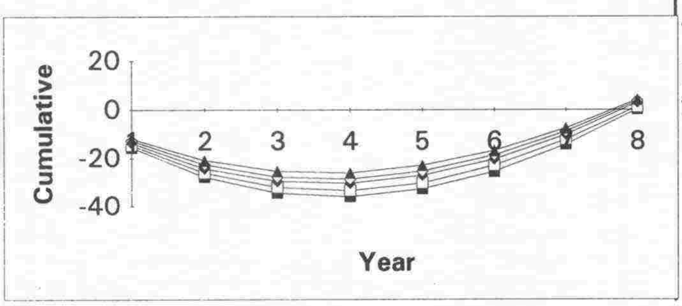
Bridges medium			*social cost*		
bm0	bm18	bm17	bm16	bm15	bm14
71	88	87	86	85	84
78	93	92	91	90	89
86	95	94	93	93	92
95	97	97	96	96	96
105	100	100	100	100	100
116	103	103	104	104	105
128	106	107	108	109	110
140	109	111	112	113	115



IRR	10%	11%	12%	13%	13%



NPV	0	1	3	4	4



Data acquisition

1. Select database file from Window menu.
2. In the data base select policy/policies .
3. Click right button. Select copy.
4. Select ECON.WLS from the Window menu.
5. Select cell A2-F2. (A2 for the reference policy)
6. Click right button. Select paste.
7. Name data set in green cell A1.

Order of colors is red, green, blue, yellow, pink.

The first figure gives social costs from each policy excepting the reference policy.

IRR gives the largest discount rate for which the investment is profitable.

The second figure shows the gain when substracted from the reference policy.

Calculation of the Net Present Value

Write the discount rate in the red cell A32. It can be changed when necessary.

NPV gives the net value of each policy with given discount rate.

The third figure gives the year, when each policy becomes profitable when compared to the reference policy.

Figure 12.

IMS Economic Analysis 20.7.1993

	85	
40	39	38
0,65	1,24	1,07
	70	
13	12	11
0,96	1,23	1,17
	23	
7	6	
0,58	0,00	0,00
	34	
37	36	35
0,88	1,24	1,09
	13	
16	14	13
0,88	0,99	0,65
	2	
6	5	
0,62	0,00	
	227	
	1,27	
	2,09	

Resource allocation between models

The yellow column contains the current allocation of resources between the six models. The yellow cells contain the first year total agency cost for each model together with their sum. Below each yellow cell we have the unit agency cost and below that the marginal user cost reduction in eight years , i.e. the user gain from the last dollar invested for each model and for the total investment. The total average denotes the average user cost reduction for all dollars invested in all of the models.

Changing resource allocation.

1. Choose one of the models by moving the cursor on one of the green or yellow cells of the model. Click left button.
2. Use either button in the bottom of the sheet to decrease or increase resources in the model.
3. Wait until calculations are updated.

Figure 13.

IMS Economic Analysis 20.7.1993

	83	
39	38	37
1,24	1,07	0,80
	59	
11	10	9
1,17	1,16	0,95
	23	
7	6	
0,58	0,00	0,00
	33	
36	35	34
1,24	1,09	0,68
	10	
12	11	10
0,83	1,05	0,94
	2	
6	5	
0,62	0,00	
	210	
	1,24	
	2,19	

Resource allocation between models

The yellow column contains the current allocation of resources between the six models. The yellow cells contain the first year total agency cost for each model together with their sum. Below each yellow cell we have the unit agency cost and below that the marginal user cost reduction in eight years , i.e. the user gain from the last dollar invested for each model and for the total investment. The total average denotes the average user cost reduction for all dollars invested in all of the models.

Changing resource allocation.

1. Choose one of the models by moving the cursor on one of the green or yellow cells of the model. Click left button.
2. Use either button in the bottom of the sheet to decrease or increase resources in the model.
3. Wait until calculations are updated.

Figure 14.

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